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Interactive Solar Panel Simulation Tool - From GHI to PV Output

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Abstract. The production and integration of solar panels is steadily growing in New Zealand and worldwide. The most common way to install solar panels in New Zealand is flat on top of the most north-facing roof. This method is used as it is space efficient, reduces mounting costs and will capture most of the sun's movement throughout the day. New Zealand homes typically have a small roof pitch. This means an installed solar panel will have a low tilt, allowing for best input in summer. However, this may not be the best result for individuals, as they may want a different outcome such as: maximum energy output in winter, maximum yearly output or a balanced output throughout each month. This paper describes a solar panel tool, which has been developed to enable users to explore interactively the impact on electricity production based on the orientation of the panels.

1 Introduction

This paper explains a solar panel simulation tool developed (nzspot.cms.waikato.ac.nz) that is designed to be interactive and enable individuals to easily see the effects on power output when changing the solar panel(s) orientation in real time. This allows the user to determine the best configuration to meet their criteria. The three stages of this simulation tool are: (1) selecting the location of the solar panel(s), (2) choosing the solar panel setup and inverter, and (3) setting the tilt and orientation of the solar panel(s). The paper then concludes by comparing the effects of different orientations on power output.

2 Location

The first stage of this tool is to determine the location of the solar panels. The user is presented with a map (Google maps) focused on New Zealand, allowing the individual to easily navigate and select their location. Once the location is picked, the tool retrieves the latitude and longitude values. With these values it is possible to estimate the sun's position, irradiance, wind speed and dry bulb temperature for anytime during the year.

2.1 Sun's position

Knowing the location of the sun is essential in estimating a solar panel's power output as it directly relates to the amount of irradiance that will hit the solar panel at a given time. The sun's position from the earth's perspective changes throughout the day because of the earth's axis of rotation and the path it follows around the sun. This tool calculates seven different variables to accurately estimate the sun's position at any time. These variables include: declination angle, equation of time, solar time, hour angle, elevation angle, zenith angle and azimuth angle.

2.2 Irradiance

With the sun's position and the solar panels location known it is possible to estimate the irradiance that will reach this location. This irradiance includes global horizontal irradiance, direct normal irradiance and diffuse horizontal irradiance.

2.2.1 Global Horizontal Irradiance (GHI)

Global Horizontal Irradiance is the total amount of radiation hitting a surface horizontal to the earth's surface. This includes both direct normal irradiance and diffuse horizontal irradiance. The tool uses the location information provided to retrieve measured GHI from the nearest weather station. The data for these weather stations is retrieved from The National Climate Database from NIWA (cliflo.niwa.co.nz).

2.2.2 Direct Normal Irradiance (DNI)

Direct Normal Irradiance describes the amount of solar radiation hitting a surface perpendicular to the sun's rays. This simulation tool uses a model developed by Laue (Laue, 1970) to estimate DNI. This model is based on air mass and a clearness index of 0.7. The 0.7 is an approximation of clearness index, since roughly 70% of solar radiation is transmitted to the earth's surface. This tool calculates the real clearness index so it is used instead.

2.2.3 Diffuse Horizontal Irradiance (DHI)

The diffuse horizontal irradiance describes the amount of solar radiation hitting a surface, which is not from direct sunlight e.g. scattered and diffused radiation. Using the equation by Maxwell (Maxwell, 1987) DHI can be estimated.

2.2.4 Wind speed and Dry Bulb Temperature

Along with GHI a further two variables that this tool retrieves from the nearest weather station are: wind speed and dry bulb temperature. These values are needed in future calculations to get a good estimate for cell and module temperature.

2.3 Summary

The first stage of this tool is simply retrieving the location of the solar panels. This tool achieves this by presenting the user with a map and allowing them to click on a location. With this location known the tool then retrieves the global horizontal irradiance, wind speed and dry bulb temperature from the closest weather station, and calculates the irradiance hitting a surface at this location. This is all done in the background to minimize the user input to achieve a simplistic and easy to use website.

3 Inverter and Module Configuration

The second step of the simulation tool is to specify the characteristics of the module (solar panel) and inverter. This tool allows users to enter their own module and inverter characteristics, or for simplicity search over a large database from Sandia labs[1], which contains hundreds of inverters and modules. This searching is simply done by clicking the specific combo box; this will present a variety of modules and inverters to select. The number of modules in series and number of parallel strings is also specified in this step.

[1] This database has hundreds of inverters and modules and is available at the National Renewable Energy Laboratory (NREL) https://sam.nrel.gov/

4 Orientation and Output

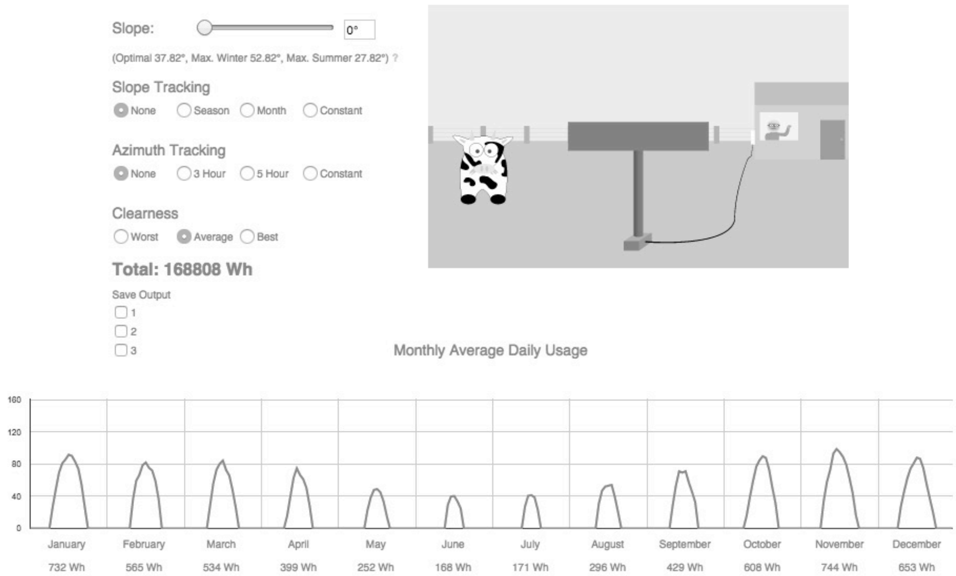

Figure 1: Last page of the tool allows the user to adjust the solar panels orientation, tracking and type of day (worst recorded day, average day and best recorded day). When adjusting these values the power output graph is updated in real time, making it visually noticeable the effects of different configurations.

The last stage of this tool is defining the module's tilt and azimuth angle. The modules tilt can be adjusted through a slider as shown in Figure 1, and the user can also choose the type of azimuth and tilt (slop) tracking. With these values known it is possible to calculate the angle of incidence between the sun's position and the module's tilt. When the angle of incidence is known it is possible to estimate the power output in four steps. The first step is to calculate the irradiance hitting the surface of the module also known as plane of array irradiance (IPOA) where POA is an acronym for plane of array. This can be calculated by adding total beam, diffuse and reflected radiation hitting the surface of the module. The second stage is using the equations proposed by Sandia Laboratories (Sandia National Laboratories and PVPMC, 2014) to estimate the cell and modules temperature, with these temperature and radiation values known we can use the Sandia PV Array Performance Model (SAPM) (King, Boyson, & Kratochvil, Photovoltaic Array Performance Model , 2004) to estimate the maximum power output of the solar panels. The final step is calculating the inverter's conversion from DC to AC power. This simulation tool uses the Sandia Performance Model for Grid-Connected Photovoltaic Inverters (King, Gonzalez, Galbraith, & Boyson, 2007). This tool also assumes that the inverter has maximum power output tracking and is able to track perfectly the maximum power output. All these calculations are done in the background, and once completed the average daily power output graph shown in Figure 1 is updated and presented to the user. This process happens in real time allowing the user to visually see the effects of changing the module's tilt and azimuth angle.

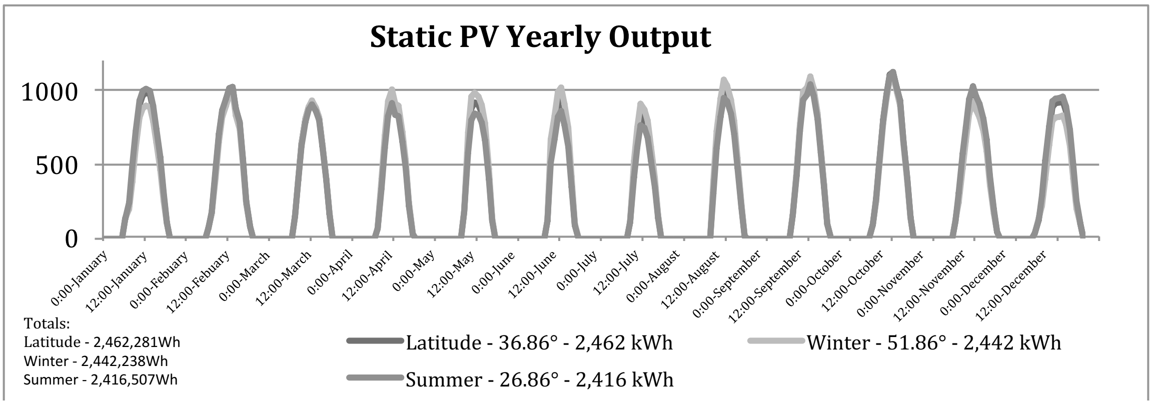

Figure 2: Graph showing different effects of solar panels' tilt in Auckland New Zealand throughout the year.

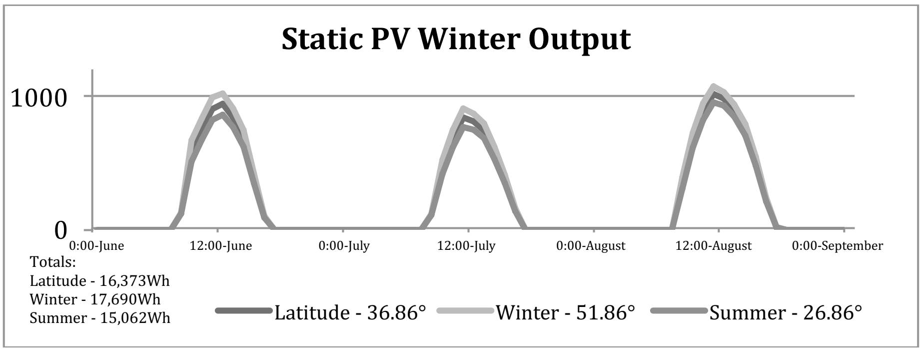

Figure 3: Graph showing different effects of solar panels' tilt throughout the winter months.

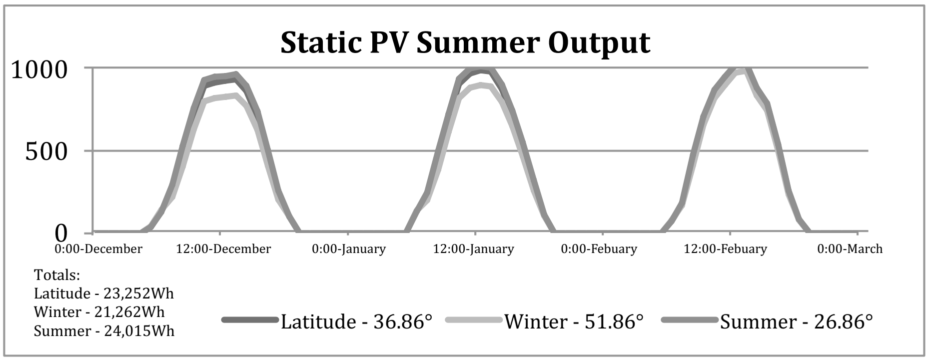

Figure 4: Graph showing different effects of solar panels' tilt throughout the summer months.

5 Results

The former sections described how this simulation tool was developed. This section is focused on looking at the results produced by this tool for different module configurations. The results are based on six 125-Watt modules in series running two in parallel making a maximum power output of 1.5 kW as shown in Table 1. The inverter is rated at a maximum of 1.5 kW, however, it is unlikely the solar panels will reach max output due to the atmospheric effects on radiation. This section describes: the effects of adjusting tilt on a static solar panel, tilt tracking, azimuth tracking and how static modules compare with single and dual axis tracking.

Module	In Series	In Parallel	Inverter	Latitude	Longitude
Mitsubishi PV-UE 125 Watt	6	2	240V HiSEL K Power 1500 Watt	-36.86	174.76

Table 1: Setup used in the tool for these results

5.1 Adjusting Tilt on a Static Solar Panel

The Authority on Sustainable Building has suggested the optimal angle for summer is -10 degrees from the angle of latitude and +15 degrees for the winter[2]. Figure 2, 3 and 4 show the tool's output with these different angles. Figure 2 shows that having a tilt equal to the latitude gives the best yearly output of 2,462 kWh, with the winter angle giving 2,442 kWh and summer with the least yearly output with only 2,416 kWh which is 46 kWh less. These values are very similar regarding yearly output, so changing the tilt between these angle values has minimal effect on yearly output with the difference between the optimal latitude angle and summer angle only being approximately 2%. However, concerning the winter months, Figure 3, the winter tilt gives the maximum output of 17,690Wh followed by latitude tilt of 16,373Wh and with the least output being the summer tilt of 15,062Wh. With these results we can see the difference between the winter tilt and latitude tilt is 8% and the difference between the winter and summer tilt being 17%. Similarly with the summer months, Figure 4, the summer tilt does produce the most output with 24,015Wh followed by the latitude tilt with 23,252Wh and the winter tilt with 21,262Wh. These results show that the summer tilt is only approximately 3% more than the latitude tilt and 13% more

2 The Document where the Authority on Sustainable Building suggest this can be found at: www.level.org.nz

than the winter tilt. This is useful information if the user wants to get the maximum output in the winter months (e.g. they might want enough power to run the electric heater in winter) or maximum power output during the summer (e.g. having enough power for a pool pump).

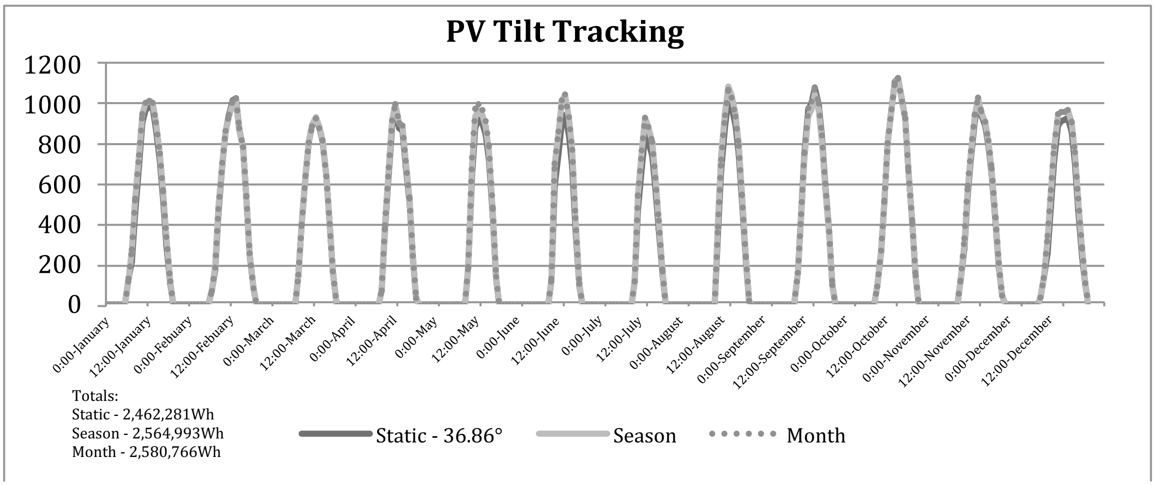

Figure 5: Graph comparing seasonal tilt tracking, monthly tilt tracking and a static PV.

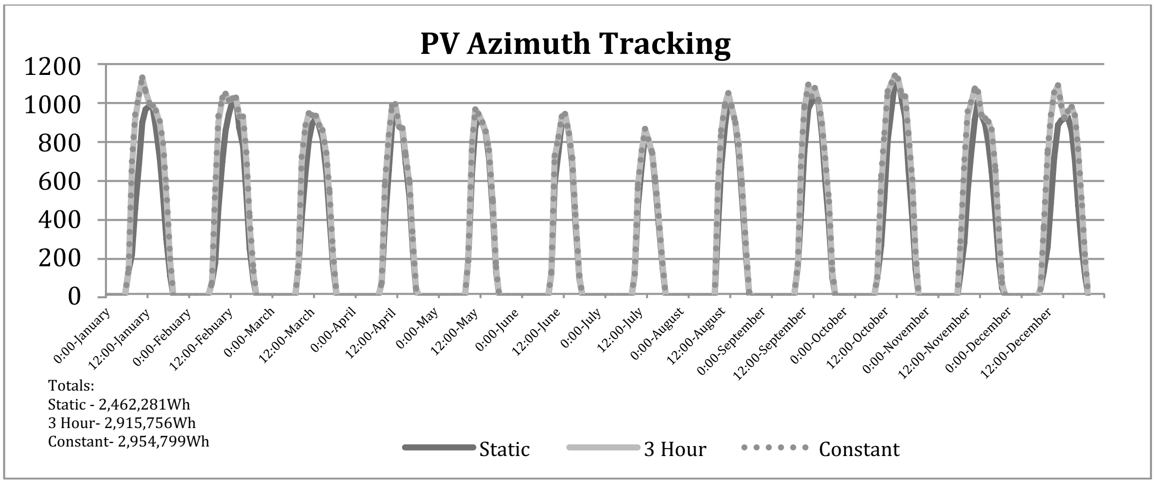

Figure 6: Graph comparing seasonal tilt tracking, monthly tilt tracking and a static PV.

5.2 Tilt Tracking

The last section shows that different solar panels at fixed tilts have a similar total yearly power output. Figure 5 shows the effects of changing the tilt every month and every season. The static fixed solar panel at a tilt of latitude gives 2,462,281Wh and changing the tilt every season would give 2,564,993Wh, which is a 4% increase. Similarly changing the tilt every month would give 2,580,766Wh, which is approximately a 5% increase. Constant tilt tracking is not added in these results because the tool simply tracks the zenith angle and does not take into consideration when the sun is behind the solar panel. This method of constant tracking would then produce even worse results than if the solar panel was flat.

5.3 Azimuth Tracking

Azimuth tracking is more focused on following the sun as it rises from the west and sets in the east. This means it captures more sunlight hours, which is more beneficial than tracking the sun's zenith angle. In Figure 6 the static solar panel provides 2,462,281Wh and 3 hour tracking (tracking the sun's azimuth angle from 11 am to 1 pm) provides 2,915,756Wh, which is approximately an 18% increase and constant tracking provides 2,954,799Wh, which is a 20% increase. This increase is considerably larger than tilt tracking, which is why most single axis tracking, follows the sun's azimuth angle rather than its zenith angle.

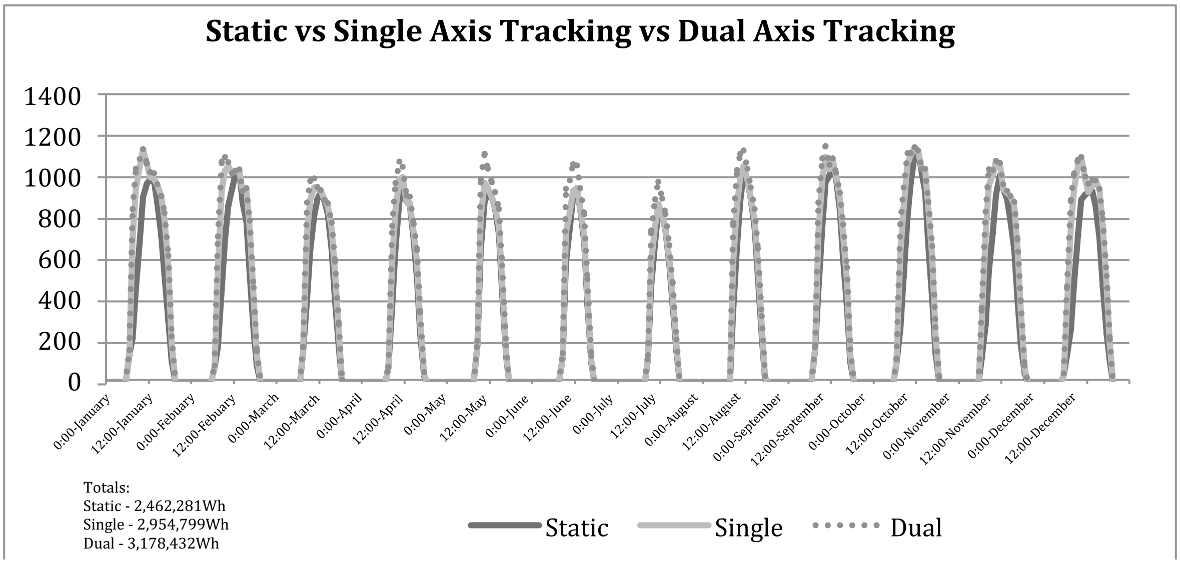

Figure 7: Graph comparing PV power output for static, single axis and dual axis tracking.

5.4 Static Tilt vs. Single Axis Tracking vs. Dual Axis Tracking

Figure 7 shows how single and dual axis tracking compare to a static angle solar panel. The single axis tracking provides an increase of 20% and dual axis provides an increase of approximately 30%. Although tracking increases the power output, it also increases the land needed and cost. The land needed for single and dual axis tracking increases to try avoid the modules casting shadows on other modules while they track the sun. The cost factor increases because of the extra parts needed initially to track the sun's position and also the ongoing cost with extra maintenance needed for these tracking parts.

5.5 Summary

It is apparent that having the solar panel at different fixed tilts can produce different power outputs at different months. If the individual wants maximum yearly power output it is suggested the tilt is as close to the latitude as possible. If maximum winter output is required, then an angle of +15 degrees on the latitude is needed. If maximum summer output is wanted, an angle of -10 degrees on the latitude is needed. Including a tracking system can increase power output, with single axis azimuth tracking giving a 20% increase and dual axis tracking with 30% increase. However, extra land and cost is needed, so further consideration by the individual is required to find out whether it is more beneficial having a tracking system or simply having more fixed solar panels. For example, dual axis tracking results in an increase of 30% but it might be more cost effective and time efficient to simply buy 30% more solar panels.

6 Conclusion

This paper describes a solar power simulation tool, which was developed to estimate a solar panel's power output at a user specified location. This tool does this in three stages. Firstly, it retrieves the location data and with this it is able to calculate the sun's position, irradiance hitting this location and estimate the wind speed and dry bulb temperature. The second stage is specifying the module and inverter configuration. The final stage is defining the orientation of the solar panel, which will simulate the power output of the solar panel(s) throughout the year. The advantage of this tool is that the user can change the orientation in real time by adjusting a slider, and immediately see the effects on power output. The user can then use these results to compare different orientations and tracking systems to find the best solution for their power requirements.

References

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