ECE 498 Research - NCSU & Reutlingen Hochschule

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1 Introduction

The ECE 498 topic being discussed within this report is a minute portion of an intercollegiate research effort attempting to integrate the electricity and heat sector to maximize efficiency in energy production. Hybrid energy systems, which couple energy production of photovoltaics (PV) and heat pumps as well as energy storage of batteries and thermal energy storages (TES), will play a pivotal role for the energy transition in buildings (Toradmal, Kemmler, and Thomas 2018). Simulink and MATLAB models are independently used to simulate the PV generators using the Klucher weather model. With differences between the supposedly identical models, the ECE 498 research within this report involves fixing the Simulink model to be indistinguishable with the MATLAB model.

2 Weather Array Data

In order to prevent any difficulty in the output of both Simulink and MATLAB models, the first step would be eliminate obscurities within the dataset being worked with. A brief visual sweep is performed on the plotted data from said dataset (Weather Array Data) to check for inconsistencies.

Title	Units	Interpolation Needed?
timevalue	-	-
zenith angle of sun	$^\circ$	Yes
azimuth angle of sun	$^\circ$	Yes
beam solar radiation on normal surface	W/m^2	-
diffuse solar radiation on horizontal surface	W/m^2	Yes
ambient temperature	C°	-
radiation temperature of sky	C°	-
relative humidity	%	-
precipitation	m/s	-
cloud index	-	-
station pressure	Pa	Yes
mean wind speed	m/s	-
wind direction	$^\circ$	-
incidence angle on surface	$^\circ$	Yes
logitudinal incidence angle	$^\circ$	-
transversal incidence angle	$^\circ$	-
direct solar radiation on surface	W/m^2	-
diffuse solar radiation on surface	W/m^2	Yes

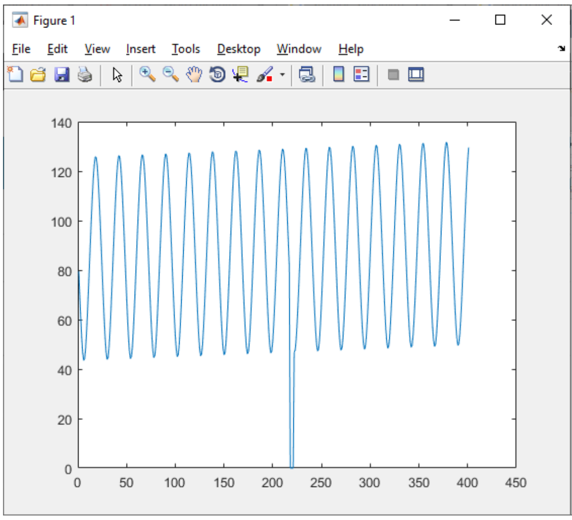

Figure 1: Before

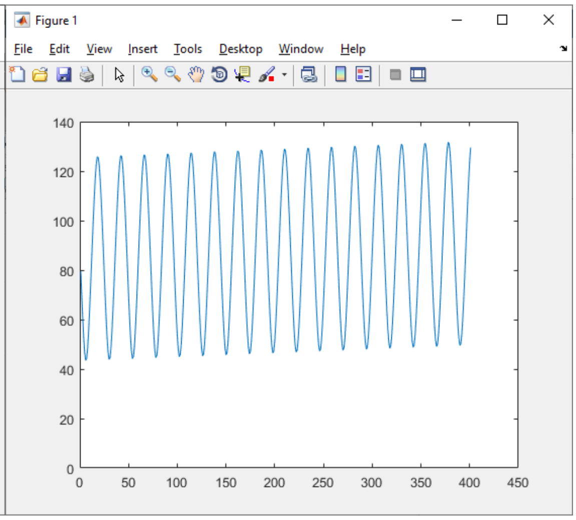

Figure 2: After

The interpolated fixes within the data can be split into two categories: continuous and patternless data. An example of an interpolated fix of continuous data is seen above in Figures 1 and 2, where the raw data for the zenith angle of the sun was interpolated. In Figure 3, the patternless data for station pressure is interpolated in a pseudo-random fashion. These interpolated fixes were done throughout the rest of the data in order to preserve accuracy of both Simulink and MATLAB models.

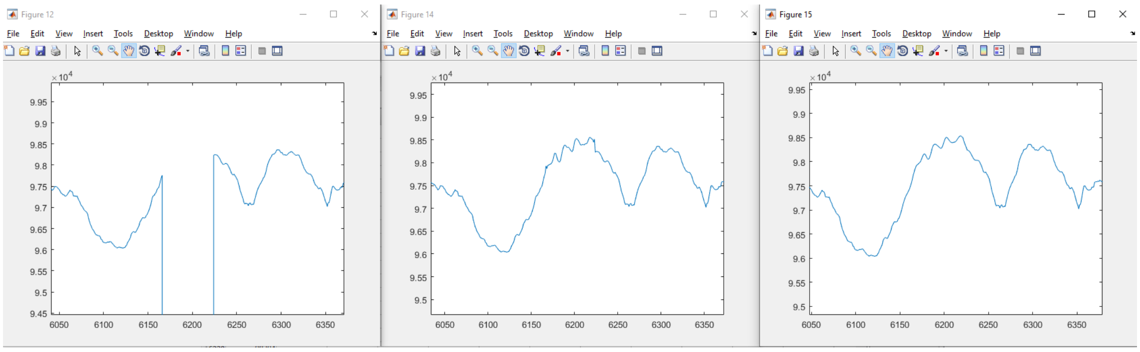

Figure 3: Station pressure interpolation process (ltr)

3 Missing CARNOT Toolbox Feature

The MATLAB model, which ideally simulates using the Klucher weather model, is what the Simulink model should be based off of. Therefore, given any differences between the two models, the Simulink model should be altered to match the MATLAB model. The Simulink model uses a third party library called the CARNOT toolbox, which is a tool to help with calculation and simulation thermal components within an HVAC system (Wohlfeil n.d.). Within the Simulink model, the PV generators are simulated using the default PV generators given within the CARNOT toolbox. However, as seen in Figure 4 below, the user can choose between an isotropic sky, Hay-Favies, or Perez 1990 weather model to simulate the PV generators. Given that the MATLAB model uses the Klucher weather model, the CARNOT PV generator block within the Simulink model must be scrapped and replaced with a new CARNOT independent block to use the Klucher model.

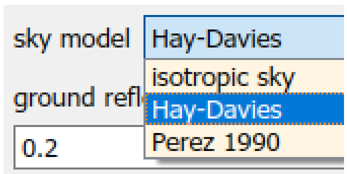

Figure 4: No option for Klucher weather model

4 Solution

4.1 Simulink Model

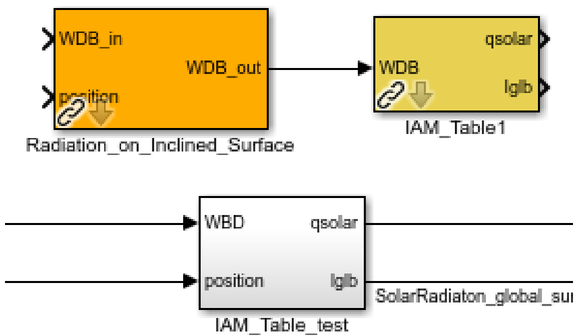

Figure 5: Radiation_on_Inclined_Surface and IAM_Table replacement shown in grey

Since the Simulink model must strip all CARNOT toolbox ties with the PV Generator, shown in Figure 5 in orange are two CARNOT toolbox subsystems which must be replaced with a subsystem using the Klucher sky model. The inputs and outputs of the subsystems (weather data bus (WDB), position, qsolar, lglb) must be maintained with the new subsystem. The entire inside of this new subsystem can be copied from the MATLAB model source code in order to generate appropriate outputs to the corresponding inputs (seen in Figure 6 below)

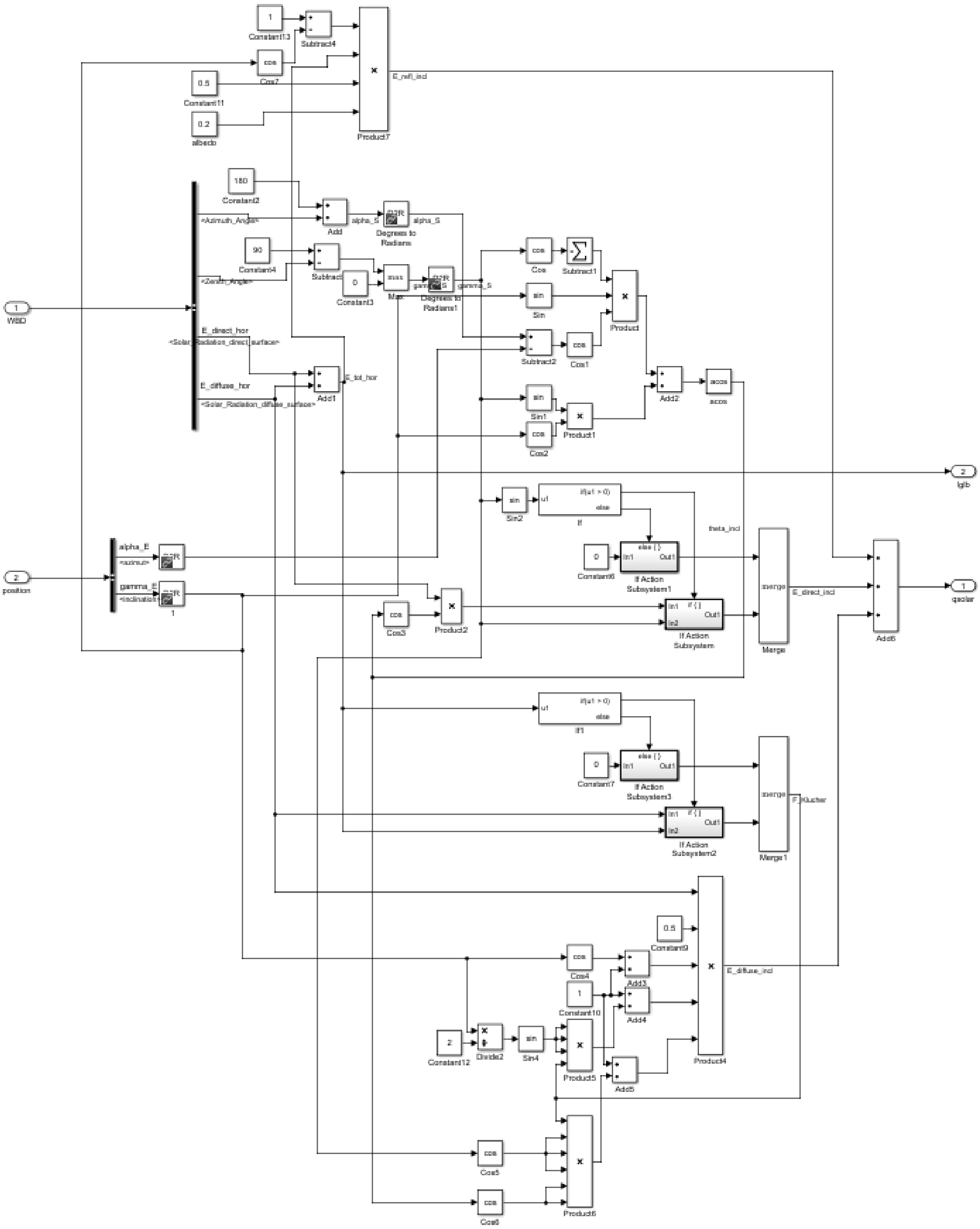

Figure 6: Replacement of both CARNOT subsystems shown in Figure 5 simulating the Klucher sky model calculations within the MATLAB function.

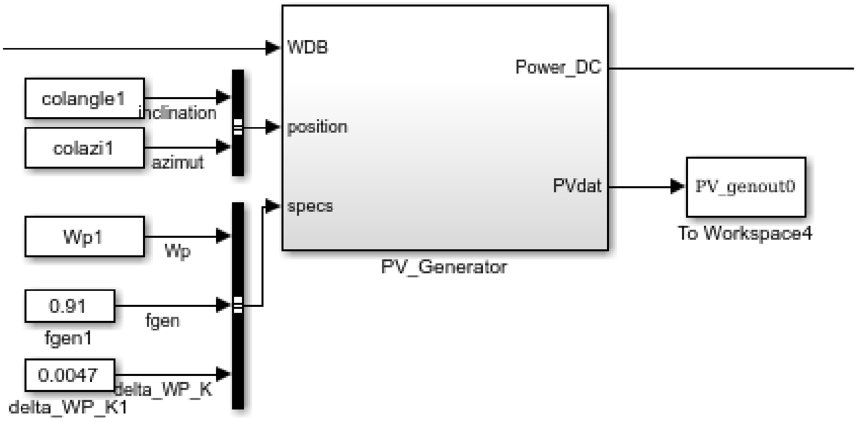

Figure 7: Replacement for the first CARNOT PV Generator block.

The PV generator blocks must be fully replaced. The previous CARNOT PV generators had certain specifications within the block that have now been converted to inputs. Seen in Figure 7, the position, peak power, factor, and temperature coefficient of the generator are all manually inputted.

Additionally, a couple changes must be made before the output of the Simulink model. To match the MATLAB model, after each PV generator is summed, a series of calculations must be made for the Klucher model output. These changes are shown in Figure 8 below.

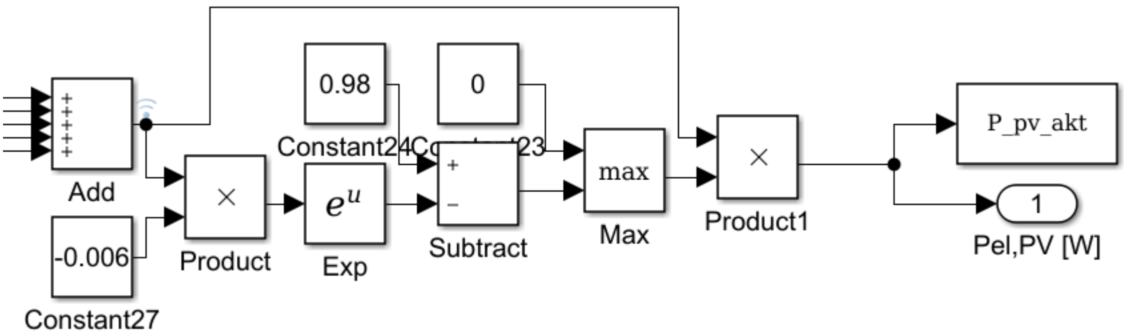

Figure 8: Adjustments near output to match Klucher model.

4.2 MATLAB Model

A couple slight changes must be made in the MATLAB model in order to match it with the Simulink one. In lines 103-105 (shown in Figure 9) E_tot_incl$_{1-5}$, fgen$_{1-5}$, and delta_WP_K$_{1-5}$ must be changed from the repeating E_tot_incl$_2$'s, fgen$_2$'s, and delta_WP_K$_2$'s in order to have an accurate output.

```
PV_el1 = fgen1*E_tot_incl1/1000*alpha_mod*Wp_1.*(1-delta_WP_K1.*((Tamb + 40*E_tot_incl1/1000)-25));
PV_el2 = fgen2*E_tot_incl2/1000*alpha_mod*Wp_2.*(1-delta_WP_K2.*((Tamb + 40*E_tot_incl2/1000)-25));
PV_el3 = fgen2*E_tot_incl2/1000*alpha_mod*Wp_3.*(1-delta_WP_K2.*((Tamb + 40*E_tot_incl3/1000)-25));
PV_el4 = fgen2*E_tot_incl2/1000*alpha_mod*Wp_4.*(1-delta_WP_K2.*((Tamb + 40*E_tot_incl4/1000)-25));
PV_el5 = fgen2*E_tot_incl2/1000*alpha_mod*Wp_5.*(1-delta_WP_K2.*((Tamb + 40*E_tot_incl5/1000)-25));
```

Figure 9: Adjustments near output to match Klucher model.

5 Conclusion & Further Research

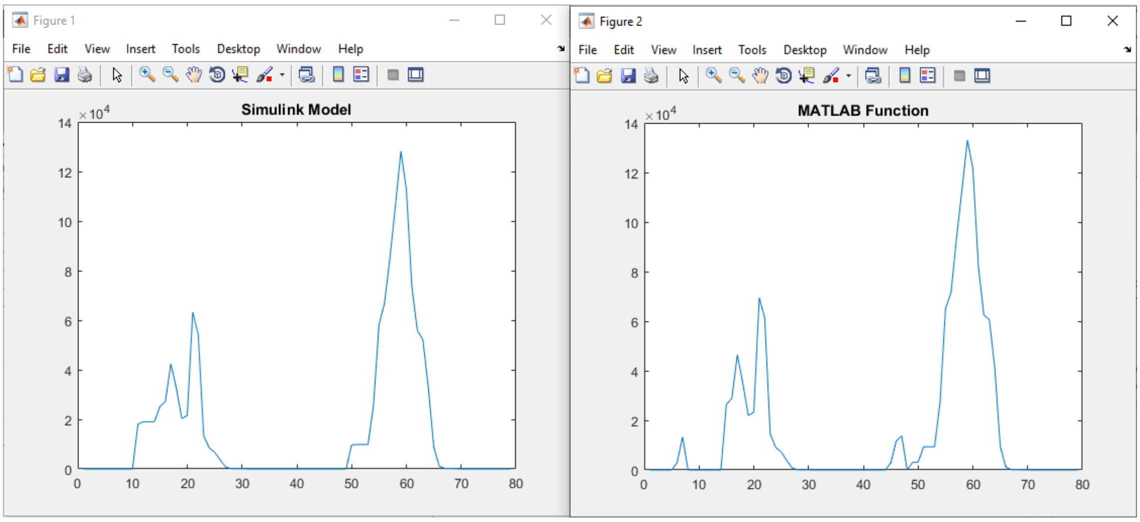

Figure 10: OLD Outputs compared from both models. Simulated 48 hours.

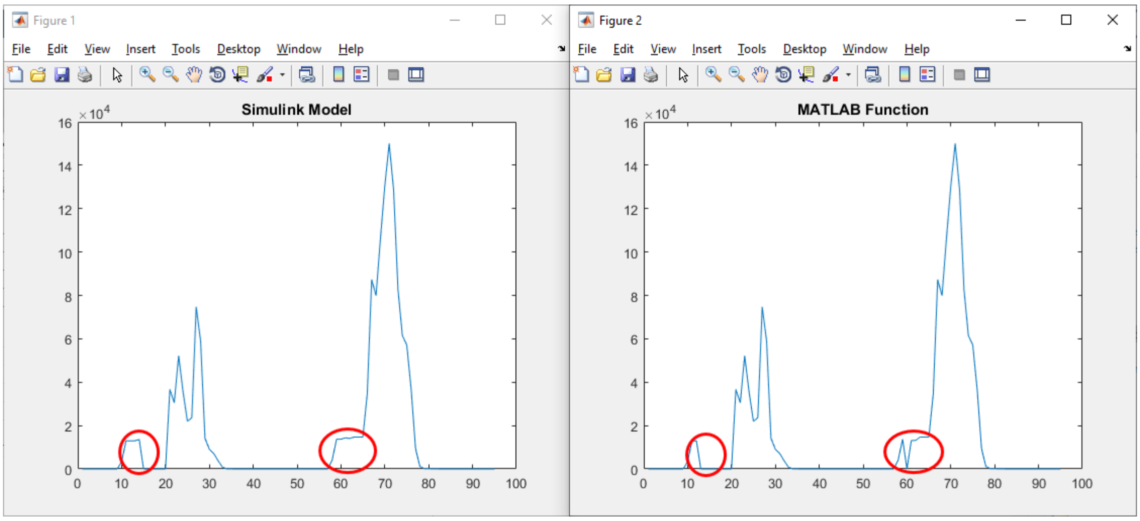

Figure 11: NEW Outputs compared from both models. Simulated 48 hours.

As seen in Figure 11 above, the new outputs are completely identical (for the most part), whereas the old outputs in Figure 10 have many small differences and inconsistencies. This is a drastic improvement as data points are beginning to match precisely in value for the new models, whereas the old models looked similar but were numerically mismatched.

Unfortunately, there is an slight lack of consistency between the new outputs of both Simulink and MATLAB models. Whenever power jumps from 0, the MATLAB model will result in a subsequent dip in the data to 0 for a short period before jumping back. Whereas for the Simulink model will result in a consistent output. This is highlighted in red in Figure 11. This pattern is consistent for however long the simulation runs, where the very beginning of each rise is inconsistent while the rest of the output is identical. It is not understood why the MATLAB function decides to dip back to 0 every single time and the Simulink model stays stagnant, and it is not known which is closest to the ideal Klucher weather model. Once this is understood, it will be easier to debug which model is incorrect and which model needs adjustment.

References

[TKT18] Ajit Toradmal, Thomas Kemmler, and Bernd Thomas. "Boosting the share of onsite PV-electricity utilization by optimized scheduling of a heat pump using buildings thermal inertia". In: *Applied Thermal Engineering* 137 (2018), pp. 248–258. ISSN: 1359-4311. DOI: https://doi.org/10.1016/j.applthermaleng.2018.03.052. URL: http://www.sciencedirect.com/science/article/pii/S1359431117359902.

[Woh] Arnold Wohlfeil. *CARNOT Toolbox*. URL: https://de.mathworks.com/matlabcentral/fileexchange/68890-carnot-toolbox.