GridLAB-D Cloud Module Specifications

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1 Overview

The cloud model for GridLAB-D is intended to replicate the effects that clouds produce on a feeder, allowing for the simulation of broader weather-related phenomena. The initial intended application is the cloud GridLAB-D-induced power transients from PV panels and possibly solar heating of residences. Other applications may be possible but will likely have to be explicitly supported through modification of the existing implementation. It is expected that the transient nature of these cloud-based effects will manifest themselves as system transients and that a typical GridLAB-D study will likely simulate a single day or less. The model will support high temporal and spatial resolutions to accurately replicate these transitory effects.

Up until this point, the outputs provided by the climate module have been global in nature: one temperature, one humidity level, one wind speed, one irradiance. Clouds are definitionally not a global phenomena and will force two important changes to the existing GridLAB-D architecture: any object wishing to use the cloud model MUST have a defined spatial location, and irradiance can no longer be considered a global value. The former is already available in GridLAB-D but is rarely used; typically the only geographical information included in feeder models is line length. The latter, though, is a completely new concept in the weather model and will require new code development in the climate module but also modification to the code of objects currently using the solar information from the climate module. If the cloud model is in use, it will not be possible for a PV installation to ask the climate module what the sun irradiance level is; it must ask what its specific irradiance is. This will require changes to the interface between the PV module and the climate module.

2 Qualitative Specification

The cloud module will be responsible for:

1. Cloud Pattern Generation - Generating a realistic cloud pattern of an appropriate size to cover all points in the feeder that need irradiance data (at a specified minimum spatial resolution).

2. Cloud Pattern Density Variation - Varying the density of the cloud pattern to follow the measured TMY2 data currently in use.

3. Cloud Pattern Location Variation - Moving the cloud pattern across the feeder according to the wind speed and direction in the TMY2 data currently in use.

4. Irradiance Value Calculation - Modifying the sun irradiance value provided to PV installations and/or residences based on the coverage determined by the current state of the cloud pattern.

2.1 Cloud Pattern Generation

The cloud pattern will be generated using the square-diamond algorithm outlined in [1] which produces cumulus-like cloud patterns. The algorithm is a well-known and well-used technique for the fractal generation of clouds and is not difficult to implement. The size of the pattern will be determined based on the coordinates of the objects that will be using the pattern. As a part of their initialization function, each object will publish its coordinates to a list that the cloud model will use to determine the size of the pattern to be generated. The pattern will have a guaranteed minimum resolution of 1 pixel = 100 m^2.

2.2 Cloud Pattern Density Variation

Naturally occurring cloud coverage density changes in time and the cloud model must be able to accomplish this. The technique outlined in [1] offers a very feasible method for doing so. The fractal pattern generated by the diamond-square technique produces a surface (xy location with a magnitude). To produce the coverage pattern this surface is sliced at an arbitrary elevation; all points on the surface below this cut are considered dark cloud and points above it are considered clear sky. To cover more of the sky with cloud the cutting elevation is increased and to create more blue sky the elevation is decreased. To alter the cloud coverage density, the cutting elevation will simply be adjusted though it will be necessary to search for the correct cutting elevation to produce the target level of coverage. The cloud coverage pattern generation is heavily randomized and there does not exist a general relationship between cutting elevation and cloud coverage.

In the expected use case, the cloud coverage density signal will come from the "Opaque Sky Cover" signal found in TMY2 datasets. The cumulus clouds are typically opaque and the use of the TMY2 measurement will allow some degree of correlation between the cloud pattern and other weather-related phenomena being simulated. Since TMY2 data is only updated hourly and the expected use-case calls for much higher time resolution, the cloud coverage density signal will be interpolated using GridLAB-D's built-in interpolation functionality for TMY datasets. A default value will be assumed if the specified field in the dataset is not available.

2.3 Cloud Pattern Location Variation

Clouds change in both shape and location over time. As in item 2, the wind speed and direction from the user provided TMY2 dataset will be used to move the clouds over the feeder model. Cumulus clouds are low elevation (less than 1000m) and though this is much higher than the 10m at which the wind TMY2 data was collected, the wind speed at the higher elevation can be estimated using an terrain roughness measurement/estimate and the measured wind speed at 10m as outlined in the European Wind Atlas [5]. As in cloud density signal a reasonable default will be assumed if the field in the TMY2 dataset is empty.

The movement of the clouds will require that new cloud patterns be generated once the edge of the pattern reaches the edge of the feeder model. Based on the upcoming wind speed and direction, the cloud module will generate additional patterns that will be stitched onto the existing pattern. The diamond square algorithm easily accommodates this by defining the leading edge of the new pattern addition with values from the trailing edge of the existing pattern. The algorithm uses these as seed values as it generates the new pattern addition, ensuring that it seamlessly integrates with the former pattern.

Just as in the the case of the changing cloud coverage density, if the wind speed and direction signal is updated at a slower rate than the simulation, values will be interpolated for all times between the recorded data points using GridLAB-D's built-in interpolation functionality.

2.4 Irradiance Value Calculation

Once the cloud pattern has been created, cut at the appropriate elevation to define the coverage density correctly, and translated to the correct position over the feeder based on the wind speed and direction, each location in the feeder needing irradiance information must be evaluated against the current cloud pattern to determine if it is shaded or not. At the beginning of the simulation, based on the provided locations for all the locations needing irradiance information, a simulated sky dome covering the needed locations will be defined. Whenever a specific location in the feeder (and hence, under this dome) needs irradiance information, the following process will take place:

- Using the existing solar angles library and based on the absolute location on the earth (using the provided latitude and longitude) as well as the time of day and day of year, the 3D angle between the location on the earth and the sun will be determined.
- Using this angle and the location of the site in question within the feeder, the point on the sky dome (P) at which the sunlight enters will be determined. This is point (P) is on the line that connects the site in the feeder and the infinitely-distant sun.
- Using this location on the sky dome, the corresponding location on a flat 2D surface will be calculate. This is the projection of the sky dome surface onto a 2D plane and will be accomplished with a technique called UV-mapping.
- The current cloud pattern will be mapped onto this 2D surface of the sky to determine if P is covered by clouds or not.
- The irradiance value for the site in the feeder will be calculated based on whether it is shaded or not.

As part of this calculation, both the clear sky and shaded irradiance values must be defined. There are several papers that provide relatively simple algebraic models for "clear " sky solar irradiance such as [2], [3], [4], and [5]. Using judicious assumptions and TMY2 extraterrestrial solar radiation values, the non-clouded irradiance values can be calculated (see below). The shading value used for locations shaded by clouds will be a constant fraction of the calculated non-clouded value, optionally defined by the user. If the user does not define this value, a default value will be used.

Using references [4] and [5] as an example, the "clear sky" solar radiation can be calculated as follows:

$$F_d = I_0 cosZ((P_R P_A)_d - a_w) P_a (P_c)_d \tag{1}$$

where

F_d is the direct horizontal radiation reaching the ground

I_0 is the extraterrestrial solar radiation, assumed constant at 1353 W/m^2

Z is the zenith angle, a function of hour of day and day of year and calculated using the existing solar angles library based on date, time and location on the globe.

$(P_R P_A)_d$ is the transmissivity after attenuation due to Rayleigh scattering and gaseous attenuation, defined as $1.041 - 0.15\sqrt{\frac{p949*10^{-5}+0.051}{M}}$ where

p is the atmospheric pressure, likely assumed constant.

M is the optical path length defined as $\frac{p}{35*101.3}\sqrt{1224cosZ^2+1}$

a_w is the absorptivity of water vapor defined as $0.077(\frac{u}{M})^{0.3}$ where

u is the precipitable water in cm, assumed to be a moderate value of 3 to 4.5 cm

P_a is the transmissivity after aerosol attenuation, defined as $e^{-\alpha M}$ assumed to be 1 as in [3]. (α is the aerosol volume absorption coefficient.)

$(P_c)_d$ is the transmissivity after cloud attenuation. For this model we will assume a constant factor of 30% (based on estimates in [1], figure 12) which can be over-ridden by the user. This factor will only be used when a given location is calculated to be covered by clouds.

The above irradiance value must be calculated at every solar installation location and will be impacted by the clouds moving over the simulated feeder. The above explanation also shows that very few assumptions need to be made that those that do (a_w, P_a, etc) have justifiable values readily available. It is not anticipated that implementing the required functions (including the above) will be particularly difficult.

3 References

[1] C. Cai and D. C. Aliprantis, "Cumulus Cloud Shadow Model for Analysis of Power Systems With Photovoltaics," Power Systems, IEEE Transactions on, vol. 28, no. 4, pp. 4496-4506, 2013.

[2] J. J. Carroll, "Global transmissivity and diffuse fraction of solar radiation for clear and cloudy skies as measured and as predicted by bulk transmissivity models," Solar Energy, vol. 35, no. 2, pp. 105-118, 1985.

[3] M. A. Atwater and J. T. Ball, "Effects of clouds on insolation models," Solar Energy, vol. 27, no. 1, pp. 37-44, 1981.

[4] M. A. Atwater and J. T. Ball, ?A numerical solar radiation model based on standard meteorological observations,? Solar Energy, vol. 21, no. 3, pp. 163?170, 1978.

[5] I. Troen, E.L. Petersen: European Wind Atlas. Ris National Laboratory, Denmark, 1989.