Solar Design Algorithm

The document below defines the calculations used to design and evaluate a PV system in preparation for creating electrical drawings.
Most of the computer code is detailed below, and the full system calculation code is found here (https://github.com/kshowalter/SPD_server/blob/master/lib/calculate_system.js). This algorithm is currently implemented in Javascript. The "Javascript" labeled boxes below is the actual code used in FSEC's application code.

Note: For each section the symbols are pre-pended by a section name when stored as a variable in the computer code, in the form of "section.symbol".

System specification

These are the what uniquely define the system design. Every other value is deterministically caclated from these variables. These are the user input in FSEC's online express design application.

Description	Symbol	Unit
Inverter manufacturer name	inverter.manufacturer_name	-
Inverter model	inverter.device_model_number	-
Module manufacturer name	array.manufacturer_name	-
Module model	array.device_model_number	-
Grid voltage	inverter.grid_voltage	V
Number of PV Source Circuits	array.num_of_strings	ea.
Total Number of Modules	array.num_of_modules	ea.
Maximum Number of Series-Connected Modules per Source Circuit	array.largest_string	ea.
Minimum Number of Series-Connected Modules per Source Circuit	array.smallest_string	ea.
Minimum Distance Above Roof (in)	module.array_offset_from_roof	in.
Grid type	interconnection.grid_type	-
Grid options	interconnection.grid_options	-
Connection type	interconnection.connection_type	-
Main panel supply OCPD rating (A)	interconnection.supply_ocpd_rating	A
Main panel busbar rating (A)	interconnection.bussbar_rating	A
Sum of inverter output overcurrent protection devices (A)	interconnection.inverter_ocpd_dev_sum	A
Sum of inverter(s) output circuit current (A)	interconnection.inverter_output_cur_sum	A
Total of load breakers (A)	interconnection.load_breaker_total	A

Constants

These are fixed values that are not calculated or provided by the user.

Description	Symbol	Limits	Value used	Unit
2% Maximum Temperature	array.max_temp	In Florida: 30 to 36	36	°C
Extreme Annual Mean Minimum Design Dry Bulb Temperature	array.min_temp	In Florida: -9 to 11	-9	°C
Maximum Voltage Rating?	array.code_limit_max_voltage	600	600	V

The most extreme temperatures are used so that the designed system is usable anywhere in Florida.

```
array.max_temp = 36;
array.min_temp = -9;
array.code_limit_max_voltage = 600;
```

Manufacturer data

The following information is taken from the manufacturer specification sheets. In our online express design application, this information is stored in FSEC's database.

Inverter:

Description	Symbol	Unit
UL1741 listed/FSEC approved?	inverter.ul_1741	-
Is inverter tranformerless	inverter.tranformerless	-
Is this a microinverter	?	V
Maximum dc voltage, Vmax,inv (V)	inverter.vmax	V
MPPT minimum dc operating voltage (V)	inverter.mppt_min	V
MPPT maximum operating voltage (V)	inverter.mppt_max	V
Min. dc operating voltage (V)	inverter.voltage_range_min	V
Min. dc start voltage (V)	inverter.vstart	V
Maximum dc operating current per inverter input or MPP tracker (A)	inverter.imax_channel	A
Number of inverter inputs or MPP trackers	inverter.mppt_channels	A
Maximum OCPD Rating (A)	inverter.max_ac_ocpd	A
Imax total	inverter.imax_total	A
Imax per MPPT channel	inverter.imax_channel	A
Max DC input power 120	inverter.max_dc_inputpower_120	W
Max DC input power 208	inverter.max_dc_inputpower_208	W
Max DC input power 240	inverter.max_dc_inputpower_240	W
Max DC input power 277	inverter.max_dc_inputpower_277	W
Max DC input power 480	inverter.max_dc_inputpower_480	W
Nominal AC output power 120	inverter.nominal_ac_output_power_120	W
Nominal AC output power 208	inverter.nominal_ac_output_power_208	W
Nominal AC output power 240	inverter.nominal_ac_output_power_240	W
Nominal AC output power 277	inverter.nominal_ac_output_power_277	W
Nominal AC output power 480	inverter.nominal_ac_output_power_480	W
Max AC output current 120	inverter.max_ac_output_current_120	V
Max AC output current 208	inverter.max_ac_output_current_208	V
Max AC output current 240	inverter.max_ac_output_current_240	V
Max AC output current 277	inverter.max_ac_output_current_277	V
Max AC output current 480	inverter.max_ac_output_current_480	V

Module:

Description	Symbol	Unit
Description	Symbol	Unit
FSEC certified	module.FSEC_approved	-
Maximum power @ STC (W)	module.pmp	W
Open-circuit voltage @ STC (V)	module.voc	V
Short-circuit current @ STC (A)	module.isc	A
Maximum power voltage @ STC (V)	module.vmp	V
Maximum power current @ STC (A)	module.imp	A
Maximum overcurrent device rating (A)	module.max_series_fuse	A
Maximum system voltage rating (V)	module.max_system_v	V
Temp Coeff Voc (%/°C)	module.tc_voc_percent	%/°C
Temp Coeff Vmp (%/°C)	module.tc_vpmax_percent	%/°C
Nameplate rating	module.nameplaterating	W

Calculations

Modules, source circuits, and array

Calculation summary:

Description	Symbol	Calculation
Maximum Power (W)	source.max_power	module.pmp * array.largest_string
Open-Circuit Voltage (V)	source.voc	module.voc * array.largest_string
Short-Circuit Current (A)	source.isc	module.isc
Maximum Power Voltage (V)	source.vmp	module.vmp * array.largest_string
Maximum Power Current (A)	source.imp	module.imp
Source Circuit Maximum Current (A), Isc x 1.25	source.Isc_adjusted	module.isc * 1.25
Voltage Correction Factor	array.voltage_correction_factor	sf.if(array.min_temp < -5, 1.12, 1.14)
Maximum system voltage Option 1 (module temp. correction factor)	array.max_sys_voltage_2	source.voc * (1 + module.tc_voc_percent / 100 * (array.min_temp - 2
Maximum system voltage Option 1 (general temp. correction factor)	array.max_sys_voltage_1	source.voc * array.voltage_correction_factor
Maximum system voltage	array.max_sys_voltage	sf.max(array.max_sys_voltage_1, array.max_sys_voltage_2)
Minimum array voltage (module temp. correction factor)	array.min_voltage	array.smallest_string * module.vmp * (1 + module.tc_vpmax_percent
Maximum Power (W)	array.pmp	array.num_of_modules * module.pmp
Open-Circuit Voltage (V)	array.voc	source.voc
Short-Circuit Current (A)	array.isc	module.isc * array.num_of_strings
Maximum Power Voltage (V)	array.vmp	module.vmp * array.largest_string
Maximum Power Current (A)	array.imp	module.imp * array.num_of_strings
PV Power Source Maximum Current (A)	array.isc_adjusted	array.isc * 1.25
PV Power Source Maximum Voltage (V)	array.vmp_adjusted	array.max_sys_voltage_2
PV Power Source Minimum Voltage (V)	array.vmp_adjusted_min	???
Enter Maximum Number of Parallel Source Circuits per Output Circuit (1-2)	array.circuits_per_MPPT	Math.ceil(array.num_of_strings / inverter.mppt_channels)
PV Output Circuit Maximum Current (A)	array.combined_isc	source.isc * array.circuits_per_MPPT
PV Output Circuit Maximum Current (A), Isc x 1.25	array.combined_isc_adjusted	module.isc * 1.25 * array.circuits_per_MPPT
Maximum PV Output Circuit Voltage at Lowest Temperature	array.max_sys_voltage_2	array.max_sys_voltage_2

```
source.max_power = module.pmp * array.largest_string;
source.voc = module.voc * array.largest_string;
source.isc = module.isc;
source.vmp = module.vmp * array.largest_string;
source.imp = module.imp;
source.Isc_adjusted = module.isc * 1.25;
array.voltage_correction_factor = sf.if( array.min_temp < -5, 1.12, 1.14);
array.max_sys_voltage_1 = source.voc * array.voltage_correction_factor;
array.max_sys_voltage_2 = source.voc * ( 1 + module.tc_voc_percent / 100 * ( array.min_temp - 25));
array.max_sys_voltage = sf.max( array.max_sys_voltage_1, array.max_sys_voltage_2 );
array.min_voltage = array.smallest_string * module.vmp * ( 1 + module.tc_vpmax_percent / 100 * ( array.max_temp - 25 ) );
array.pmp = array.num_of_modules * module.pmp;
array.voc = source.voc;
array.isc = module.isc * array.num_of_strings;
array.vmp = module.vmp * array.largest_string;
array.imp = module.imp * array.num_of_strings;
array.isc_adjusted = array.isc * 1.25;
array.vmp_adjusted = array.max_sys_voltage_2;
array.circuits_per_MPPT = Math.ceil( array.num_of_strings / inverter.mppt_channels );
array.combined_isc = source.isc * array.circuits_per_MPPT;
array.combined_isc_adjusted = module.isc * 1.25 * array.circuits_per_MPPT;
array.max_sys_voltage_2 = array.max_sys_voltage_2;
```

The maximum array voltage is must not exceed the maximum system voltage allowed by the module.

```
error_check['array_test_1'] = array.max_sys_voltage > module.max_system_v;
if(error_check[ 'array_test_1' ]){ report_error( 'Maximum system voltage exceeds the modules max system voltage.' );}
```

The maximum array voltage is must not exceed the maximum system voltage allowed by the building code.

```
error_check['array_test_2'] = array.max_sys_voltage > array.code_limit_max_voltage;
if(error_check[ 'array_test_1' ]){ report_error( 'Maximum system voltage exceeds the maximum voltage allows by code.' );}
```

The maximum array voltage is must not exceed the maximum system voltage allowed by the inverter.

```
error_check['array_test_3'] = array.max_sys_voltage > inverter.vmax;
if(error_check[ 'array_test_1' ]){ report_error( 'Maximum system voltage exceeds the inverter maximum voltage rating' );}
```

The minimum array voltage must be greater than the inverter minimum operating voltage.

```
error_check['array_test_4'] = array.min_voltage < inverter.voltage_range_min;
if(error_check[ 'array_test_1' ]){ report_error( 'Minimum Array Vmp is less than the inverter minimum operating voltage.' );}
```

The total array power must be less than 10,000W.

```
error_check.power_check_array = array.pmp > 10000;
if( error_check.power_check_array ){ report_error( 'Array voltage exceeds 10kW' );}
```

The combined DC short circuit current from the array must be less than the maximum allowed per inverter MPPT channel.

```
error_check.current_check_inverter = array.combined_isc > inverter.imax_channel;
if( error_check.current_check_inverter ){ report_error( 'PV output circuit maximum current exceeds the inverter maximum dc
current per MPPT input.' );}
```

Inverter

If max_ac_ocpd is not provided by the manufacturer, it is calculated as follows:

AC_OCPD_max = max_ac_output_current * 1.25

The nominal_ac_output_power is selected from fields based on the user selected grid voltage. As an example, if the user selects 240 VAC, then:

nominal_ac_output_power = nominal_ac_output_power_240
max_ac_output_current = max_ac_ouput_current_240

```
inverter.AC_OCPD_max = sf.if( sf.not( inverter.max_ac_ocpd ), inverter.max_ac_output_current * 1.25, inverter.max_ac_ocpd );
inverter.nominal_ac_output_power = inverter['nominal_ac_output_power_'+inverter.grid_voltage];
inverter.max_ac_output_current = inverter['max_ac_ouput_current_'+inverter.grid_voltage];
```

Interconnection

At least one of the following checks must not fail:

- The sum of 125 percent of the inverter(s) output circuit current and the rating of the overcurrent device protecting the busbar exceeded the ampacity of the busbar.
- The sum of 125 percent of the inverter(s) output circuit current and the rating of the overcurrent device protecting the busbar exceeded 120 percent of the ampacity of the busbar.
- The sum of the ampere ratings of all overcurrent devices on panelboards exceeded the ampacity of the busbar.

```
interconnection.check_1 = ( ( interconnection.inverter_output_cur_sum * 1.25 ) + interconnection.supply_ocpd_rating ) >
interconnection.bussbar_rating;
interconnection.check_2 = ( interconnection.inverter_output_cur_sum * 1.25 ) + interconnection.supply_ocpd_rating >
interconnection.bussbar_rating * 1.2;
interconnection.check_3 = ( interconnection.inverter_ocpd_dev_sum + interconnection.load_breaker_total ) >
interconnection.bussbar_rating;

error_check.interconnection_bus_pass = sf.and( interconnection.check_1, interconnection.check_2, interconnection.check_3 );
if( error_check.interconnection_bus_pass ){ report_error( 'The busbar is not compliant.' )};
```

The panel's main OCPD must not exceed the bussbar rating.

```
error_check.interconnection_check_4 = interconnection.supply_ocpd_rating > interconnection.bussbar_rating;
if( error_check.interconnection_check_4 ){ report_error( 'The rating of the overcurrent device protecting the busbar exceeds the
rating of the busbar. ' )};
```

Conductor and conduit schedule

For string inverters, this is the circuit names:

- exposed source circuit wiring
- pv dc source circuits
- mppt dc input circuits
- inverter ac output circuit

```
var circuit_names = [
'exposed source circuit wiring',
'pv dc source circuits',
'mppt dc input circuits',
'inverter ac output circuit',
];
circuit_names.forEach(function(circuit_name){
circuits[circuit_name] = {};
});
```

```
circuits['exposed source circuit wiring'].max_current = source.isc;
circuits['exposed source circuit wiring'].max_voltage = source.voc;
circuits['exposed source circuit wiring'].total_cc_conductors = ( array.num_of_strings * 2 );
circuits['exposed source circuit wiring'].total_conductors = ( array.num_of_strings * 2 ) + 1;
circuits['exposed source circuit wiring'].temp_adder = sf.lookup( module.array_offset_from_roof, tables[1] );
circuits['pv dc source circuits'].max_current = source.isc;
circuits['pv dc source circuits'].max_voltage = source.voc;
circuits['pv dc source circuits'].total_cc_conductors = ( array.num_of_strings * 2 );
circuits['pv dc source circuits'].total_conductors = ( array.num_of_strings * 2 ) + 1;
circuits['mppt dc input circuits'].max_current = source.isc; //* array.circuits_per_mppt;
circuits['mppt dc input circuits'].max_voltage = source.voc;
circuits['mppt dc input circuits'].total_cc_conductors = ( inverter.mppt_channels * 2 );
circuits['mppt dc input circuits'].total_conductors = ( inverter.mppt_channels * 2 ) +1;
circuits['inverter ac output circuit'].max_current = inverter.max_ac_output_current;
circuits['inverter ac output circuit'].max_voltage = inverter.grid_voltage;
circuits['inverter ac output circuit'].total_cc_conductors = inverter.num_conductors - 1;
circuits['inverter ac output circuit'].total_conductors = inverter.num_conductors;
```

For each circuit, calculate the following.

```
circuit_names.forEach(function(circuit_name, i){
  //circuits[circuit_name] = {};
  //logger.info(circuit_name);
  var circuit = circuits[circuit_name];
  circuit.id = i;



  circuit.power_type = sf.index( ['DC', 'DC', 'DC', 'AC', 'AC'], circuit.id );
  circuit.temp_adder = sf.if( circuit.temp_adder, circuit.temp_adder, 0 );
  circuit.max_conductor_temp = array.max_temp + circuit.temp_adder;
  circuit.temp_correction_factor = sf.lookup( circuit.max_conductor_temp, tables[2] );
  circuit.conductors_adj_factor = sf.lookup( circuit.total_CC_conductors , tables[3] );
  circuit.min_req_cond_current_1 = circuit.max_current * 1.25;
  circuit.min_req_cond_current_2 = circuit.max_current / ( circuit.temp_correction_factor * circuit.conductors_adj_factor );
  circuit.min_req_cond_current_3 = circuit.max_current * 1.25 * 1.25;
  circuit.min_req_cond_current = sf.max( circuit.min_req_cond_current_1, circuit.min_req_cond_current_2 );
  circuit.min_req_OCPD_current_DC = sf.max( circuit.min_req_cond_current_1, circuit.min_req_cond_current_2,
circuit.min_req_cond_current_3  );
  circuit.min_req_OCPD_current = sf.if( circuit.power_type === 'DC', circuit.min_req_OCPD_current_DC,
circuit.min_req_cond_current_1);
  circuit.OCPD_required = sf.index( [false, false, false, true, true ], circuit.id );
  circuit.ocpd_type = sf.index( ['NA', 'PV Fuse', 'NA', ' Circuit Breaker', 'Circuit Breaker'], circuit.id );
  circuit.OCPD = sf.lookup( circuit.min_req_OCPD_current, tables[8], 0, true, true);
  circuit.min_req_cond_current = sf.if( circuit.OCPD_required, circuit.OCPD, circuit.min_req_OCPD_current );
  circuit.conductor_current = sf.lookup( circuit.min_req_cond_current, tables[4], 0, true);
  circuit.conductor_size_min = sf.lookup( circuit.conductor_current, tables[4] );
  circuit.conductor = sf.index( ['DC+/DC-, EGC', 'DC+/DC-, EGC', 'DC+/DC-, EGC', 'L1/L2, N, EGC', 'L1/L2, N, EGC, GEC'],
circuit.id );
  circuit.location = sf.index( ['Free air', 'Conduit/Exterior', 'Conduit/Interior', 'Conduit/Interior', 'Conduit/Exterior'],
circuit.id );
  circuit.material = 'CU';
  circuit.type = sf.index( ['PV Wire, bare', 'PV Wire, bare', 'THWN-2', 'THWN-2', 'THWN-2, bare'], circuit.id );
  circuit.volt_rating = 600;
  circuit.wet_temp_rating = 90;
  circuit.conductor_strands = sf.lookup( circuit.conductor_size_min, tables[5], 2 );
  circuit.conductor_diameter = sf.lookup( circuit.conductor_size_min, tables[5], 3 );
  circuit.min_req_conduit_area_40 = circuit.total_conductors * ( 0.25 * PI() * sf.lookup( circuit.conductor_size_min, tables[5],
3 ) ^2 );
  circuit.conduit_type = sf.index( ['NA', 'Metallic', 'Metallic', 'Metallic'], circuit.id );
  circuit.min_conduit_size_PVC_80 = sf.lookup( circuit.min_req_conduit_area_40, tables[6] );
  circuit.min_conduit_size_EMT = sf.lookup( circuit.min_req_conduit_area_40, tables[7] );



  ///////
  // cleanup for display
  if( ! circuit.OCPD_required ){
    circuit.ocpd_type = '-';
    circuit.OCPD = '-';
  }
  circuit.conductor_size_min = circuit.conductor_size_min + ', ' + circuit.conductor_size_min;
});
circuits['exposed source circuit wiring'].conductor_size_min = '10, 10';
```