You may carry out this assignment with collaboration

Problem 1 (100pts)

In class we looked at a process for matching solar modules to inverters for proper operation and power production. Let’s review this process with a detailed calculation for a solar farm that is designed to have a nameplate capacity of 100MW.

Refer to the slides from Session 15. Use the 300W modules described in class, with these characteristics:

<table>
<thead>
<tr>
<th>Table 4.1 Technical data for 300 Wp monocrystalline PV module</th>
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</thead>
<tbody>
<tr>
<td><strong>Electrical characteristic</strong></td>
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<tr>
<td>Maximum power at STC ($P_{\text{MAX}}$)</td>
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<tr>
<td>Optimum operating voltage ($V_{\text{MP}}$)</td>
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<tr>
<td>Optimum operating current ($I_{\text{MP}}$)</td>
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<tr>
<td>Open circuit voltage ($V_{\text{OC}}$)</td>
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<td>Short circuit current ($I_{\text{SC}}$)</td>
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<td>Temperature co-efficient of $V_{\text{OC}}$</td>
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<tr>
<td>Temperature co-efficient of $P_{\text{MAX}}$</td>
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<tr>
<td>Maximum series fuse rating</td>
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<td>Maximum system voltage</td>
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<tr>
<td>Number of cells</td>
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<td>Power tolerance</td>
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</table>

Also, assume the temperature range is:

$$5^\circ\text{C} \leq T \leq 70^\circ\text{C}$$

Use inverters as described in class, with these characteristics:
Employ the temperature correction calculations as shown in class for

a. Voltage at the maximum power point at highest temperature

\[ V_{MPP}(T_{HIGH}) = V_{MPP}(T_{STC}) + (\gamma_P \cdot (T_{HIGH} - T_{STC})) \]

b. Open circuit voltage at lowest temperature

\[ V_{OC}(T_{LOW}) = V_{OC}(T_{STC}) + (\gamma_V \cdot (T_{LOW} - T_{STC})) \]

c. Assume the short circuit current is independent of temperature

\[ I_{SC}(T) = I_{SC}(T_{STC}) \]
Part (1) Armed with this information, calculate the following:

1. The minimum number of modules in a string
2. The maximum number of modules in a string
3. The maximum number of parallel strings permitted on each inverter
4. Select a system configuration, i.e., total number of sub-arrays and strings per sub-array, compatible with the inverters
5. Show that your combination of strings and sub-arrays will produce 100MW

Determine whether all 5 of these calculations lead to a feasible solution, that is, are there any inconsistencies in the module or inverter characteristics or proposed temperature range or some other factor that may not allow the 100MW farm to be designed as requested. If your initial calculations lead to an infeasible solution, what could be changed to make the design self-consistent?

Calculation 1. The minimum number of modules in a string is determined by the minimum MPP voltage over the temperature range. This voltage is found at the highest temperature expected, or 70°C:

\[ V_{MPP,T} = \left( V_{MPP,STC} + \gamma_p(T - T_{STC}) \right) \]

\[ V_{MPP,70} = \left( V_{MPP,STC} + \gamma_p(T - T_{STC}) \right) = 32 + (-0.134V/C)(70 - 25) = 26.1V \]

Note 1: The MPP voltage is 32 V as shown in Table 4.1, line 2

Note 2: The factor -0.134 V/C is equal to the coefficient given in Table 4.1, line 7, multiplied by the MPP voltage as described in Note 1

\[ (-0.42\% \times 32V) = (-0.0042 \times 32V) = -0.134 V/C \]

The minimum number of modules is:

\[ N_{min} = \frac{V_{MPPT, min}}{V_{MPP,70}} = \frac{596V}{26.1V} = 22.8 \rightarrow 23 \]

Note 3: The MPPT minimum voltage is 596 V as shown in Table 4.2, line 2

Calculation 2. The maximum number of modules in a string is determined by the maximum open circuit voltage over the temperature range. This voltage is found at the lowest temperature expected, or 5°C:

\[ V_{OC,T} = \left( V_{OC,STC} + \gamma_v(T - T_{STC}) \right) \]
\[ V_{OC,5} = (39.5 - 0.122 \times (5 - 25)) = 41.9 \text{V} \]

Note 1: The Open Circuit voltage is 39.5 V as shown in Table 4.1, line 4

Note 2: The factor -0.122 V/C is equal to the coefficient given in Table 4.1, line 6 multiplied by the Open Circuit voltage listed in Note 1

\[ (-0.31\% \times 39.5\text{V}) = (-0.0031 \times 39.5) = -0.122 \text{ V/C} \]

The maximum number of modules is:

\[ N_{\text{max}} = \frac{V_{\text{inverter,max}}}{V_{OC,5}} = \frac{1000}{41.9} \approx 23.9 \quad \text{yields} \quad 23 \]

Note 3: The Inverter maximum voltage input is 1000 V as shown in Table 4.2, line 2

This poses a problem. The minimum and the maximum number are identical – 23 modules. It will be shown later that strings with 23 modules will not be able to produce a 100MW system, with the above selected inverter. Another issue is the prime number 23 – the string cannot be divided into several rows with equal numbers of modules. This complicates the actual installation in the field.

So – I propose using 24 modules per string. But to permit that, one must find an alternate module, or a different temperature range. Rearrange the last equation for \( N_{\text{max}} \)

\[ V_{OC,5} \leq \frac{V_{\text{inverter,max}}}{N_{\text{max}}} = \frac{1000}{24} = 41.7 \text{ V} \]

So look at the equation for \( V_{OC,5} \). This can be made to be 41.7 or smaller by:

1. Finding a module with a smaller temperature coefficient. If -0.31\% were changed to -0.28\%, then the \( V_{OC} \) would become 41.6\V
2. Changing the allowed temperature range. If the minimum allowed temperature were changed to 7\C, then \( V_{OC} \) would again be 41.6\V

Option 2 is easier, so let’s proceed with that. Going forward, let us use 24 modules as the number per string

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Calculation 3. The maximum number of parallel strings to each inverter is found from:
Calculation 4. Determine a system configuration

The inverter will accept 24 modules per string; the maximum number of strings to the inverter is 140. Each inverter can accept 9 DC inputs – each one of these connects to a sub-array of strings. But the 140 strings cannot be divided evenly among the 9 inputs. One sensible option to get 140 strings in 9 inputs:

- **Four sub-arrays, each with 15 strings (60 strings total)**
  - PLUS
- **Five sub-arrays, each with 16 strings (80 strings total)**

Calculation 5. Verification of power output

Each inverter has a rated DC power of 1010kW – so a 100MW array needs 100 central inverters.

1. One module can yield 300 W_{DC} (optimal conditions)
2. One string of 24 modules can produce (24 x 300W) = 7200 W = 7.2 kW_{DC}
3. 140 strings can produce (140 x 7200W) = 1,008,000 W_{DC} = 1008 kW_{DC} = 1.008 MW_{DC}
4. One inverter will accept 1.010 MW_{DC}
   - **Note 1: Item 3 and Item 4 are self-consistent!!**
5. 100 inverters would accept 101 MW_{DC}
   - **Note 2: If we had used 23 modules per string, each inverter could only accept 0.97 MW_{DC}, and the entire farm would yield 96.6 MW – short of the 100MW required!**
Part (2) The 100MW system will require 100 1-MW inverters. So one could view this as a design project for a 1MW system repeated 100 times, and each 1MW system thought of as a sub-array connected to produce the 100MW array. Draw a sketch of the 1MW sub-array system, showing the arrangement of the modules in the strings, the strings as inputs to the 9-input inverter, and the location of the inverter. Alter this figure (for a different PV system, shown in Messenger and Abtahi’s text) to help you with the layout. Adjust the row lengths to accommodate the number of modules per string and input.

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In the simplest possible form, a 15 string input is shown below. Each box contains 24 modules connected in series to form one string to sum the voltages. Each string is connected in parallel to sum the currents.

A 16 string input would be similar, maybe 4x4 in layout.

The next page shows the 9 inputs (4 of 15, 5 of 16, to produce 140 string array) going into the inverter.

**Input #3 – 15 strings of 24 modules/string (connected in parallel)**

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24 modules per box (string)

To inverter, input #3
Block diagram, 9 inputs going into the inverter

15 strings

15 strings

Input #3
15 strings

15 strings

16 strings

Input #6
16 strings

16 strings

16 strings

16 strings

9 input inverter