Micro Irrigation Engineering

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Lecture - 50
Tutorial 10 – Numerical Examples on Solar PV Irrigation System

Hello participants of micro irrigation engineering subject. I am inviting you to lecture 50 of this subject. Lecture 50, deals with tutorial 10 in which we have solved numerical problems on solar PV irrigation system. In lecture 48 and 49 we have discussed about solar PV system, integration of solar PV system with micro irrigation pumps and then the theoretical aspects of this particular topic we have discussed in those lectures.

Now in this particular lecture we will be dealing some of the theories problems which are to go more insight about this particular topic. So, here we will discuss about solar PV power output and design of solar PV system.

So, question 1 here we are required to determine cell temperature, we are required to determine open circuit voltage, we are required to determine maximum power output for 150 standard module which has been given under the condition of 1 sun insolation and ambient temperature of 30 degree Celsius. This particular module has rating of open circuit voltage of 42.8 Volt which is given by Voc means we are in the short form we are telling as a Voc and short circuit current it is given as Isc of 3.5 Ampere. The temperature coefficient for voltage drop is 0.37% per degree Celsius, power drop is 0.5% per degree Celsius. The module has a nominal operating cell temperature in short form we say NOCT of 47 degree Celsius. So, we have been given these data.

Once again, I am reading the given data that is nominal power, module power that is a Pn is 150 Watt. This particular observation is being taken at the ambient temperature of 30 degree Celsius, NOCT is 47 degree Celsius, Voc is 42.8 Volt, and Isc is 3.5 Ampere. Standard solar insulation value is also available to us that is 1000 Watt per square meter and temperature coefficient for the voltage which we give by the symbol alpha is 0.37% per degree Celsius.

Temperature coefficient for the power drop which we give by the symbol gamma equal to 0.5% per degree Celsius. So, these are the available data from this we have been asked to determine cell temperature, open circuit voltage, and maximum power output voltage. So, this is the data, from these data, these three parameters we will estimate. This estimation is done by standard formula and those standard formulas which I read here.

The cell temperature is estimated by using expression that is

$$T_{cell} = T_{amb} + \left(\frac{NOCT-20}{800}\right)\times G$$

So, these data already I told you that T ambient is given NOCT is given and G is given. So, we are just simply substituting in this expression to find out the cell temperature. So, when we substitute this value T ambient as 30 degree Celsius, NOCT is given 47 degree Celsius and G is given as 1000. So, when we substitute, we get cell temperature as 63.75 degree Celsius.

Now from the given data we are required to find out what is the new open circuit voltage. So, Voc is given for the standard condition. Now Voc we are required to obtain by using the expression here.

$$V_{OC} = V_{oc} \times \left[1 - \alpha\left(T_{cell} - 25\right)\right]$$

So, we have been given in the question Voc, we have been given the value of alpha, T cell we have just now we have calculated. So, we are substituting to obtain new value of open circuit voltage.

So, new value of open circuit voltage is estimated by simply substituting these values that is Voc is given as 42.8 Volt and then alpha is given 0.0037 then Tcell we have estimated 63.75 degree Celsius. So, after we substitute, we get new open circuit voltage as 36.66 Volt. Then maximum power output that is a Pmax is given by

$$P_{max} = P_n \times \left[1 - \gamma\left(T_{cell} - 25\right)\right]$$

so Pn is al also given to us, gamma is also given to us in the question, T cell we have estimated. So, Pmax means maximum power output is estimated by using this expression and by using this expression we will substitute the values which is given in the question and then we will estimate. So, what when we are substituting Pn is given at 150, gamma is given at 0.005 so and then this, we have estimated Tcell as a 63.75 degree Celsius. So, we get 120.93. So, we had a value of 150 now this is reduced.

So, Pmax it is reduced because of the Tcell temperature of 63.75. So, there is a drop in the rated power so this drop in the rated power has been estimated that is 150 minus 120 divided by 150. So, that we will get the significant drop of 19% from its rated power of 150. So, this way it has been estimated the all three parameters have been estimated.

Now question 2, here we have been given data that a solar based micro irrigation system has a PV array rated at 1 kilowatt under standard test conditions. So, means this is the rated value of one kilowatt under standards test condition. Now the PV array operates at 20 degree Celsius ambient temperature. So, this is the data which is available that ambient temperature is 20 degree Celsius. The module nominal operating cell temperature that is a NOCT is 47 degree Celsius, DC power output at the MPP drops by 0.5% per degree Celsius above standard test condition at temperature of 25 degree Celsius. So, there is a power drop by 0.5% per degrees Celsius. So, this information is also given and then PV system has 3% array loss due to mismatched modules. So, this value is given that a 3% is the loss due to mismatching of the modules and 4% loss due to deposition of dirt and dust.

So, this is another value which is available. Now inverted it operates at 90% efficiency. So, we are required to determine the output from PV system in AC form that is alternative current means this is given to us we are required to find out AC output from the PV system.

So, the PV array power is 1 kilowatt is given, ambient temperature is given, 20 degree Celsius and NOCT is given 47 degree Celsius, standard insolation power it is falling on the panel that is 1000 Watt per square meter, temperature coefficient drop is 0.5% per degree Celsius. So, same formula which we used in previous question 1, so this we are using here also.

$$T_{cell} = T_{amb} + \left(\frac{NOCT-20}{800}\right)\times G$$

So, we have been given T ambient and is 20 degree Celsius. So, we are substituting here NOCT is given that is a 47 degree Celsius and this is the standard formula minus 20 divided by 100 multiplied by G, G is given as a 1000. So, we are substituting and we get the cell temperature as 53.75 degree Celsius.

Now with the power loss at 0.5 degree Celsius per degree above 25 degree Celsius, this is the important information. The DC rated power of the array would be estimated as Pdc that is the power rated from your DC rated power is given by

$$P_{dc} = P_n \times \left[1 - \gamma\left(T_{cell} - 25\right)\right]$$

So, we will use this expression to obtain the value of Pdc. So, just simply we are substituting the value.

We have been given Pn as 1 kilowatt then we have estimated T cell as 53.75 this value of gamma is also available that is 0.005 that is 0.5% per degree Celsius. So, 0.005 we are substituting here and 25 it is in the formula. So, after substituting this value we are getting Pdc that is your DC rated power of array, so this is 0.856 kilowatt. Now including mismatch factor means this also information is given to us mismatch factor we have been given the delt factor is also given to us. We have been given the inverter efficiency. So, we will substitute to get the value of AC power output estimated in the previous system. So, Pac that is a power output in terms of AC power output we can say that is equal

$$P_{ac} = P_{dc} \times mismatch\,factor \times dirt\,factor \times inverter\,efficiencies$$

So, we have got Pdc at 0.856 multiplied by the mismatch factor because 3% it is given.

So, we will get this particular factor means in terms of the coefficient. So, this is coming as 0.97 and then the delta factor that is 4%. So, this value will be in the terms of the coefficient this is we are getting as 0.96 multiplied by the inverted efficiency of 0.90. So, the AC power output Pac equal to 0.717 kilowatt is the answer.

Now coming to question 3. In question 3, we have been given information that the I-V characteristic of a PV module at standard test condition is shown in the figure given below. This is the figure which we have been given. So, current and voltage characteristics of PV module is given in this figure. We are required to determine fill factor and also it has been asked that how much will be the efficiency of PV module if it has a surface area of 1 square meter.

So, this is the diagram which is available this diagram has been given in the next page also. So, I am just putting here to explain you more from this diagram. So, from this diagram or figure what we are seeing that when this particular graph has been plotted between the current I and voltage V. So, what we see this particular data when it is plotted, we find that Isc is here it is a 7.5 ampere. This is Isc that is the short circuit current and then we have got the voltage Voc equal to 21.5. So, this dotted line gives us the value of Isc as well as open circuit voltage, we have got these two value. Now from this diagram we also see that when this is a plotted this particular diagram so at this particular point the maximum power is available at 120 kilowatt. So, this is another value which we are getting that this is the trend of the curve which has changed from this.

So, this is the P max, maximum power as 120 watt and then standard solar insulation value is also available that is 1000 watt per square meter. So, from this curve what we see here at 120 Watt the value of maximum current we get that is Im equal to 7 Ampere. And the corresponding value if you see here corresponding value of Vm that is voltage so maximum voltage is 17 at this point that is a 17 volt. So, at P 120 that is a maximum power of 120 Watt from this particular diagram Im is 7 ampere, Vm is 17 volt. Now fill factor has been calculated by using these values which we have obtained from this I-V curve. So, fill factor is given by

$$FF = \frac{I_m \times V_m}{I_{SC} \times V_{OC}}$$

So, all these values are now available to us from this particular figure. So, we are just simply substituting 7 multiplied by 17 divided by 7.5 multiplied by 21.5 so fill factor equal to 0.74.

Now efficiency of the PV module is estimated by using this expression

$$\eta = \left(\frac{FF \times I_{SC} \times V_{OC}}{1000 \times A}\right) \times 100$$

So, fill factor we have estimated, Isc already we have got from the figure, Voc also we have got from the figure and A is given to us. So, A is given as 1 square meter. So, just simply we are substituting the values that is FF that is a fill factor is 0.74 for we have estimated Isc is 7.5, Voc is 21.5. So, multiplication of these values that is 0.74 into 7.5 into 21.5 divided by 1000 multiplied by area 1 so into 100. So, this is coming as 11.9 are 12%. So, efficiency of the PV module is 12%.

Now question 4, we have been given data that a pump is required to deliver water 100 cubic meter per day from a well having average static water level of 20 meter. So, we are required to deliver this is the demand that is 100 cubic meter per day the demand and a well which is given where static water level is 20 meter. A drip irrigation system is installed to irrigate 2.5 hectare orchard. So, area is given to us as 2.5 hectare. Total head loss from major and minor components of drip irrigation system is 6 meter. So, head loss is major head loss, it is frictional head loss and minor head loss due to connector's, fittings and couplers. So, this all those losses which are occurring because of these connections are minor head loss. So, some of these two losses is equal to 6 meter this is available to us. The operating pressure required to operate drip emitter is 1 kg per square centimetre.

So, this is the head requirement that should be available then our dripper will operate. So, 1 kg per square centimetre equal to 10 meter of water column. From manufacturer's catalogue, a PV module of 320 Watt power capacity is selected. So, this information is available that one particular PV module which is delivering 320 Watt that particular module has been selected which has maximum current and voltage rating of 8.74 Ampere and 36.61 Volt, respectively.

So, current is 8.74 Ampere, voltage is 36.61 Volt. The submersible pump has voltage rating of 420 Volt for the head up to 50 meter. So, up to 50 meter this much voltage rating it is available. Now we are required to determine there are three components which has been asked in this question. We are required to determine the pump capacity assuming overall pump efficiency and inverter efficiency as 60%. So, pump efficiency is 60% and inverter efficiency as 95%. Second part of the question it has been asked the size of solar PV system required to fulfil the water demand if the location has average daily 4.5 hour one insulation per insulation means one insulation it is delivering in every day 4.5 hours sunshine is available. This is another data and the derating factor is 20%.
So, the derating factor is available. 4.5 hours solar insolation at the standards standard was insolation of 1000 that is a 4.5 hour it is available and we have been given information is 60% is the pump efficiency and 95% is the inverter efficiency.

These data once again it is given here and just to make you understand we have been given the daily requirement of the pump is 100 cubic meter per day, static water level hs is 20 meter, the heat loss due to friction and minor losses in including both the losses, it is 6 meter, the operating pressure to operate the dripper is 10 meter, maximum current that is Im is 8.74 Ampere, maximum voltage Vm is 36.61 Volt. Maximum power that is a Pmax available from the panel which has been selected that is a 320 Watt and then the number of hours in a standard insulation is 4.5 hours per day. This is also available efficiency of the pump is 60%, inverter efficiency is 95% and derating factor is 20%. So, having given these data our aim is to this much amount of water so production goal that is water production goal is 100 cubic meter per day.

So, required pumping rate is estimated by Q equal to daily demand that is 100 cubic meter per day divided by hours of insulation that is given to us that is a 4.5 hours and that is multiplying factor. So, when we are substituting this value, we get required pumping rate equal to 100 divided by 4.5 that is your hours of insulation and multiplied by 60. So, when we divide this 4.5 into 60 so we get 0.37 cubic meter per minute or we can say 6.17 litre per second is the required pumping rate which is equivalent to 100 cubic meter per day, this is the demand.

Total dynamic head, we will estimate, we have been given static water head, we have been given major and minor head losses, we have been given the operating head of the emitter. So, all these things when we are summing means total dynamic head Ht is equal to 20 meter plus 6 meter plus 10 meter equal to 36 meter. The pump capacity in kilowatt we will be estimating by using the expression

$$Pump\ input\ power\ (kW) = \frac{9.81 \times Ht\ (m) \times Q(Ls^{-1})}{pump\ efficiency \times invertor\ efficiency \times 1000}$$

So, when we get this when we substitute the value 9.81 multiplied by the total Ht that is total dynamic head is 36 meter this we have calculated and then the discharge in litre per second which we calculated 6.17 litre per second. Pump efficiency is 60% the inverter efficiency is 95% multiplied by 1000 to get the value in kilowatt.

So, we are getting 3.82 kilowatt which is when we are dividing with the 0.746 because 746 Watt equal to 1 horsepower. So, when we are getting it that is 3.82 divided by 0.746 and kilowatt so this becomes your 5.12 horsepower. So, this is the answer.

Now number of PV panel when we want to estimate in series. So, this can be given by

$$Module\ in\ series\ = \frac{DC\ Pump\ voltage\ (V)}{Module\ voltage\ (V)}$$

So, module in series, we are given that is 420 pump voltage. Now when we want to convert AC voltage from the DC point of view so DC voltage is when multiplied by square root 2. So, this we are multiplying with the square root 2 so 420 multiplied by root 2 divided by 36.61. So, we get 16.22 are 17 number of panels. So, modules in series is 17 numbers. Now number of module string in parallel, it is estimated by using the expression

$$PV\ strings\ in\ parallel\ = \frac{Pump\ input\ power\ (W)}{modules\ in\ series \times Module\ voltage (V) \times Module\ current (A) \times Derating\ factor}$$

So, pump input voltage we have already estimated, number of module in series already we have got 17 number. Module voltage is available to us, module current is also available to us and then the rating factor is also available to us.

So, when we are estimating it, we have got the values at 3820 kilowatt divided by 17 into 36.61 into 8.74 multiplied by derating factor. So, the derating factor is 1 minus 0.2. So, we get here 0.88, which is nothing but 1 so one module is in parallel. So, the PV system capacity is estimated by module in series multiplied by module in parallel multiplied by module power capacity. So, this can be given simply we have got 17 into 1 into 320 is the capacity of a single module. So, this is coming at 5440 Watt which is equivalent to 5.40 kilowatt. So, hence 17 number of PV panels of 320 Watt power capacity is sufficient to deliver desired pump power requirement of 3.82 kilowatt. So, this is our answer and this is the interpretation of this particular question.

So, we estimated these things and now to get more insight more experience you are solving problems, so you may refer these books for more details. Let me summarize the whole thing. In this lecture we discussed about power from solar PV module, we also estimated operating cell temperature, fill factor and how to estimate the efficiency of PV module. And then pump and PV system design also has been estimated in the last question. In forthcoming lecture, we will discuss about automation of micro irrigation system part one. Thank you very much.