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Component Selection Criteria & Sizing of Solar PV System

Japen Gor
GORenewable Technology
Ahmedabad, India

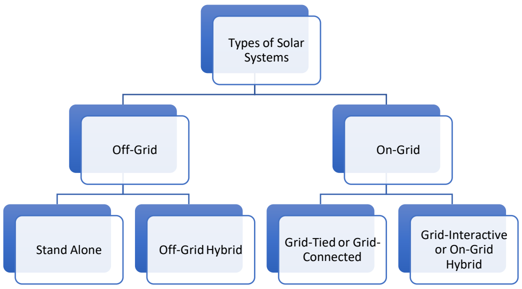
***Abstract*—The paper focuses on explanation of Solar PV System Designing, Component sizing and selection based on the practical experience as a consultant in Solar PV industry. Designing of On-Grid-Grid-Tied Solar PV System is taken into consideration for complete system designing.**

Keywords*— Solar Photovoltaic Systems, On-grid Solar System, Grid-Tied Solar PV Systems, System Designing, Component Sizing, Component Selection.

I. INTRODUCTION

Use of solar photovoltaic systems is increasing day-by-day. It is one of the best portable renewable energy solutions in modern times. Due to lack of understating of functioning and critical design parameters installers often end up installing incorrect size of components together. The paper focuses on delivering the details understanding component selection including and not limited to solar PV Modules, inverters, cables and safety switches. The method explained in the paper is completely based on the practical experience of an author.

II. TYPES OF SOLAR SYSTEMS



III. SIZING OF GRID-TIED OR GRID-CONNECTED (ON-GRID) SOLAR PV SYSTEMS

Components to be sized/calculated

1. Solar Modules/Panels
2. Inverter (Selection)
3. DCDB (DC Fuse, DC MCB, DC SPD)
4. ACDB (AC Fuse, AC MCB, AC SPD)
5. DC Cable
6. AC Cable

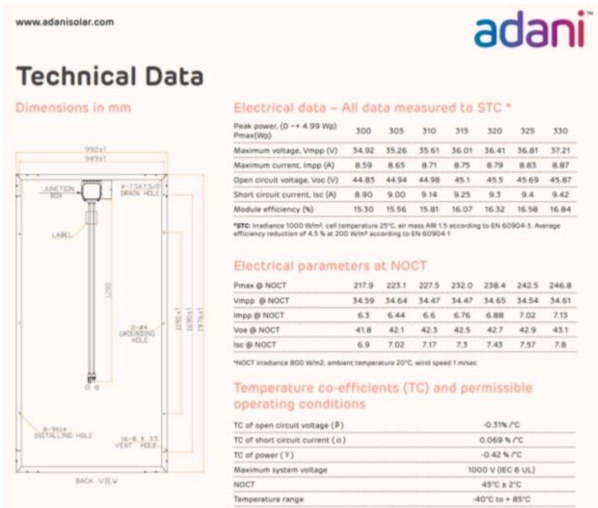
A. Steps of System Sizing

Step 1: Module Calculations
Step 2: Inverter Selection
Step 3: Strings and Arrays of Modules
Step 4: Calculations of Balance of System (BOS)
Step 5: Simple Single Line Diagram (SLD)

B. Practice Question 1: System sizing for 4 kWp (DC)

Step 1: Module Calculations

There are many solar module manufacturers.
It is important to select appropriate module manufacturer/supplier.
Ever module manufacturer makes different ratings of modules. i.e., 250Wp, 300Wp, 320Wp, 325Wp, 335Wp etc…
<u>It is important to receive updated datasheet from manufacturer/supplier and keep it handy while doing the system sizing.</u>



www.adanisolar.com

adani

Technical Data

Dimensions in mm

Electrical data – All data measured to STC *

Peak power, (0 ~+ 4.99 Wp) Pmax(Wp)	300	305	310	315	320	325	330
Maximum voltage, Vmpp (V)	34.92	35.26	35.61	36.01	36.41	36.81	37.21
Maximum current, Impp (A)	8.59	8.65	8.71	8.75	8.79	8.83	8.87
Open circuit voltage, Voc (V)	44.83	44.94	44.98	45.1	45.5	45.69	45.87
Short circuit current, Isc (A)	8.90	9.00	9.14	9.25	9.3	9.4	9.42
Module efficiency (%)	15.30	15.56	15.81	16.07	16.32	16.58	16.84

*STC: Irradiance 1000 W/m², cell temperature 25°C, air mass AM 1.5 according to EN 60904-3. Average efficiency reduction of 4.5 % at 200 W/m² according to EN 60904-1

Electrical parameters at NOCT

Pmax @ NOCT	217.9	223.1	227.5	232.0	238.4	242.5	246.8
Vmpp @ NOCT	34.59	34.64	34.47	34.47	34.65	34.54	34.61
Impp @ NOCT	6.3	6.44	6.6	6.76	6.88	7.02	7.13
Voe @ NOCT	41.8	42.1	42.3	42.5	42.7	42.9	43.1
Isc @ NOCT	6.9	7.02	7.17	7.3	7.43	7.57	7.8

*NOCT irradiance 800 W/m2, ambient temperature 20°C, wind speed 1 m/sec

Temperature co-efficients (TC) and permissible operating conditions

TC of open circuit voltage (β)	-0.31% /°C
TC of short circuit current (α)	0.069 % /°C
TC of power (γ)	-0.42 % /°C
Maximum system voltage	1000 V (IEC & UL)
NOCT	45°C ± 2°C
Temperature range	-40°C to + 85°C

(Source: https://www.adanisolar.com/Downloads)

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Mechanical data

Length	1976 mm
Width	992 mm
Height	35 mm / 40 mm
Weight	22 Kg (35 mm) / 27 Kg (40mm)
Junction box	IP67
Cable and connectors	1200 mm length cable, MC4 & Amphenol compatible connectors
Application class	Class A (Safety class II)
Superstrate	High transmittance ARC glass
Cells	72 multi-crystalline solar cells; 4 bus bars, 156.75 x 156.75 mm
Cell encapsulation	Superior dielectric strength & PID resistant EVA
Substrate	Tri layer backsheet
Frame	Anodized aluminium frame with twin wall profile
Mechanical load test as per IEC & UL	5400 Pa-front ; 2400 Pa-back
Maximum series fuse rating	15 A

Packing information

Container	40'HC
Pallets / Container	22
Pieces / Container	660

Warranty and certifications

Product warranty**
25 years linear power warranty

Performance guarantee**
Power Degradation < - 2.5 % in first year
< - 0.68 % / year in 2-25 years

Approvals and certificates: IEC 61215 Ed2, IEC 61730, IEC 61701, UL 1703, MCS, JET, CEC, CEC-Aus, IEC 62716

Note:
• The specifications included in this datasheet are subject to change without notice.
• The electrical data given here is for reference purpose only.
• Please confirm your exact requirements with the sales representative while placing your order.

*Caution:
Please read safety and installation instructions before using the product.

** Warranty:
Please read Adani solar warranty documents thoroughly.

MSPV/MDL/PDM/Spec/03

Adani Solar" is the brand name for legal entity "Mundra Solar PV Ltd." having its registered office at "Adani House, Nr Mithakhali Six Roads, Navrangpura, Ahmedabad 380 009, Gujarat, India" and manufacturing unit at "Revenue Survey No: 180/P City: Kutch Taluka: Mundra, Village: Tunda, Post office: Bidada; Pin: 370535".

(Source: https://www.adanisolar.com/Downloads)

Out of above options let us assume we select 325Wp modules as modules to be used for our project.

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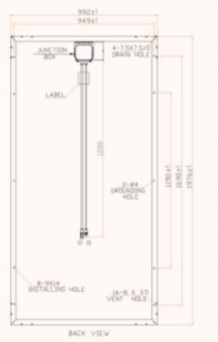

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TC of short circuit current (α)	0.069 % /°C
TC of power (γ)	-0.42 % /°C
Maximum system voltage	1000 V (IEC & UL)
NOCT	45°C ± 2°C
Temperature range	-40°C to + 85°C

So Now, Parameters of selected modules are as follows

- Wp = 325Wp
- Voc = 45.69V
- Vm = 36.81V
- Isc = 9.40A
- Im = 8.83A

Temperature has vital effect on performance of PV modules. Output and life of PV modules have direct connection with the surrounding temperature, however for sizing of system we are not going to consider the effect of temperature in such method of sizing.

Effect of Temperature

Temperature has vital effect on performance of PV modules. Output and life of PV modules have direct connection with the surrounding temperature.

All Solar Modules are tested at 25 Deg. C.

With increase in temperature, Voltage of Module decreases and current increases. However, % decrease of V is higher than % increase of I hence overall power output decreases.

Eg.

For selected 325 Wp panel, performance of module at 45 Deg. C is expected as follows.

Temperature co-efficients (TC) and permissible operating conditions

TC of open circuit voltage (β)	-0.31% /°C
TC of short circuit current (α)	0.069 % /°C
TC of power (γ)	-0.42 % /°C
Maximum system voltage	1000 V (IEC & UL)
NOCT	45°C ± 2°C
Temperature range	-40°C to + 85°C

Rise in surrounding temperature is 45 – 25 Deg. C. = 20 Deg. C

Deduction in Voltage would be = 0.31% x 20 Deg. C. = 6.2%

Rated Voc (@25 Deg. C.) = 45.87V

Hence Voc @45 Deg. C = 45.87 – (45.87 x 0.062) = ~43.03V

Rise in surrounding temperature is 45 – 25 Deg. C. = 20 Deg. C

Rise in Current would be = 0.069% x 20 Deg. C. = 1.38%

Rated Isc (@25 Deg. C.) = 9.40A

Hence Isc @45 Deg. C. = 9.40 + (9.40 x 0.0138) = ~9.53A

Please remember Pm = Im x Vm and same calculation are to be done for Vm and Im instead Voc and Isc to determine the loss in power due to rise in temperature.

For the purpose of sizing of the system we are not going to consider above calculations in this method of sizing of system.

Now,

Total No. of Solar Modules required = System Size (DC)/Wp of Chosen Modules

= System Size (DC)/Wp of Chosen Modules

= 4000Wp (DC)/325Wp

= ~12.31 Nos.

Here

If we select 12nos of 325Wp modules total system size would be = 325Wp x 12 = 3900Wp = **3.9kWp**

And

If We select 13nos of 325Wp modules total system size would be = 325Wp x 13 = 4225Wp = **4.225kWp**

In practical scenario the selection of number of modules depends on various factors like

1. State policy
2. Space available
3. Energy required
4. Budget
5. Designer's ideology

Here for sake of calculations we select 13nos of 325Wp panels and hence our updated system size would be **13nos x 325Wp = 4.225kWp**

Step 2: Inverter Selection

Grid-Tie Solar Inverter

KSolare Energy Pvt. Ltd.

Technical Datasheet

Single Phase

Model (KSY)	1 KW	1.2 KW	1.5 KW	2 KW	2.2 KW	3 KW	3.2 KW	3.3 KW	4 KW	4.2 KW	5 KW	5.2 KW	5.3 KW	6 KW	6.2 KW
Input (DC)															
Nominal Input Power (KW)	1	1.2	1.5	2	2.2	3	3.2	3.3	4	4.2	5	5.2	5.3	6	6.2
Max Peak DC Input Power (KW)	1.2	1.4	1.8	2.4	2.6	3.6	3.8	4	4.8	5	6	6.2	6.4	6.5	6.6
Max. DC I/P (V dc)	500V DC														
Max. MPPT I/P Current(A)	10A								10A						
MPPT Short Circuit Current(A)	15A								15A						
MPPT Tracking Voltage(Vdc)	70-500V			100-500V											
Min. Start Voltage(V)	80V			120V											
Number of MPPT Tracker	1								2						
strings per MPPT Trackers	1														

Three Phase

Model (KSY)	5 KW	6 KW	7 KW	8 KW	9 KW	10 KW	12 KW	15 KW	18 KW	20 KW	25 KW	30 KW	33 KW	35 KW	40 KW	50 KW	60 KW	70 KW	80 KW
Input (DC)																			
Nominal Input Power (KW)	5	6	7	8	9	10	12	15	18	20	25	30	33	35	40	50	60	70	80
Max Peak DC Input Power (KW)	6	7	8	9	10	12	13.5	17.5	20	22	27.5	33	36	38.5	44	55	66	77	88
Max. DC I/P (V dc)	1000V DC																		
Max. MPPT I/P Current(A)	20A											28.5							
MPPT Short Circuit Current(A)	26 Amps											37 Amps							
MPPT Tracking Voltage(Vdc)	200-850V																		
Min. Start Voltage(V)	250VDC/ 150VDC(low) & 1000 VDC(High)																		
Number of MPPT Tracker	2														3		4		
strings per MPPT Trackers	1							2				3						3 / 4	

(Souce: https://ksolare.com/product-4/)

For On-Grid Systems, generally the DC capacity and AC capacity (of inverter) are very much similar.

Hence here we shall look for inverter which can take min. 4.225kWp (DC) input.

Looking at datasheet, 4.0kW inverter (Model: KSY 4kW) has **"Max Peak DC Input Power"** of 4.8kWp and hence that inverter serves the purpose.

Here we select KSY 4kW inverter for our calculations and make note of important parameters next.

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Note: every single detail mentioned on datasheet are important however for the purpose of calculations and demonstration we shall focus on few as follows.

- Nominal Input Power: 4kW
- Nominal AC output power: 4kW
- Max Peak DC Input Power: 4.8kW
- Max Peak Output Power: 4.4kW
- MPPT Tracking Voltage: 100-500V
- Max output current AC: 19.1A
- Min. Start Voltage: 120V
- No. of MPPT Trackers: 2
- Strings per MPPT Trackers: 1
- Max MPPT I/P Current: 10A
- MPPT Short Circuit Current: 15A

One of the most important point in datasheet is to identify the maximum DC input that can be connected to Inverter, and this detail can be decided based on

No. of MPPT Trackers and Strings per MPPT Tracker

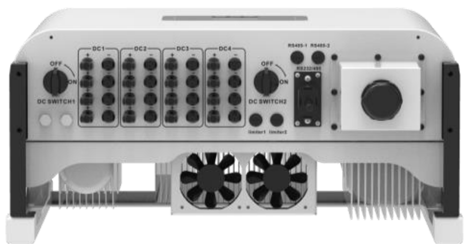
No. of Total Inputs (Total Strings) Available
= No. of MPPT Tracker x Strings per MPPT Tracker

in our case
No. of Total Inputs (Total Strings) Available
= 2 x 1 = 2.

(Source: https://ksolare.com/)
Inverter with 2 MPPTs and 1 string in each MPPT, Total possible string connection: 2


(Source: https://vhil.in/ksolare-2-kw-single-phase-solar-on-grid-inverter/)
Inverter with 1 MPPTs and 2 strings in each MPPT
Total possible string connection: 2


(Source: https://www.indiamart.com/proddetail/ksolar-15kw-3-phase-solar-grid-tie-inverter-22785960633.html)
Inverter with 2 MPPTs and 1 string in each MPPT
Total possible string connection: 2


(Source:https://www.deyeinverter.com/product/three-phase-string-inverter/sun30-33-35-40-50kg03.html)
Inverter with 4 MPPTs and 4 string in each MPPT
Total possible string connection: 16

Step 3: Strings & Arrays of Modules

For On-Grid Systems we try to keep voltage of DC and AC as high as possible (with in inverter and grid permissible limits).
Hence here we shall try to make as many series connection as possible among the modules since in series connections voltage adds up.
Remember:
Series connection of any electrical component is known as STRING
&
Parallel connection of any electrical component is known as ARRAY
Max. No. of Modules in a Series
= Max. MPPT (I/P DC) Voltage of Inverter/Voc of Module
= 500/45.69
= 10.94
=~ 10 (Always Round Down)

Electrical data – All data measured to STC *

Peak power, (0 ~+ 4.99 Wp) Pmax(Wp)	300	305	310	315	320	325	330
Maximum voltage, Vmpp (V)	34.92	35.26	35.61	36.01	36.41	36.81	37.21
Maximum current, Impp (A)	8.59	8.65	8.71	8.75	8.79	8.83	8.87
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Input (DC)													
Nominal Input Power (KW)	1	1.2	1.5	2	2.2	3	3.2	3.3	4	4.2	5	5.2	5
Max Peak DC Input Power (KW)	1.2	1.4	1.8	2.4	2.6	3.6	3.8	4	4.8	5	6	6.2	6
Max. DC I/P (V dc)	500V DC												
Max. MPPT I/P Current(A)	10A								10A				
MPPT Short Circuit Current(A)	15A								15A				
MPPT Tracking Voltage(Vdc)	70-500V		100-500V										
Min. Start Voltage(V)	80V		120V										
Number of MPPT Tracker	1								2				
strings per MPPT Trackers	1												

No. of Strings (Input to Inverter)
= Total No. of Modules/Max. No. of Modules per string
= 13/10
= 1.3
= ~ 2 (Always Round Up)
Hence arranging 13 modules in 2 strings
= 13/2

Hence arranging 13 modules in 2 strings
= 13/2
S1 = 7 Modules
S2 = 6 Modules
Or
S1 = 6 Modules
S2 = 7 Modules

Step 4: Calculations of BOS
SPDs
There are mainly three types of SPDs as follows
Type I – Permanently Connected, Hard-Wired, intended for installation between secondary of the service transformer and line side of main service equipment.
Type II – Permanently Connected, Hard-Wired, intended for installation on load side of the main service equipment
Type III – Called 'Point of Utilization SPDs', to be installed at a minimum conductor length of 10 meter from electrical service panels.

DCDB (DC Fuse, DC MCB, DC SPD)
Ratings of DC Fuse and DC MCB
= Isc (of string) x 1.25
= 9.4A x 1.25
= 11.75A
=~15A
Hence
DC Fuse Rating = 15A
DC MCB Rating = 15ADC SPD Rating = Type II

ACDB (AC Fuse, AC MCB, AC SPD)
Ratings of AC Fuse and AC MCB
= Imax (AC output of Inverter) x 1.56
= 19.1A x 1.56
= 29.796A
=~30A
Hence
AC Fuse Rating = 30A
AC MCB Rating = 30A
AC SPD Rating = Type II

DC Cable
As per government regulations, DC Cable must be minimum 4sq.mm.
Hence here we shall consider
Cu. 1C 4sq.mm. DC Cable

TYPE 1 – Current Carrying Capacity

SOLAR DC CABLES AS PER TUV SPECIFICATIONS-2 PfG 1169/08.2007

Single Core Size in	Tinned Copper Maximum Resistance @20°C	Current Carrying Capacity of DC Solar Cable with XL-LSOH Insulation and XL-LSOH Sheathing at 60°C		
		Single Cable in Air	Single Cable on Surface	2 Adjacent Cables on Surface
Sq.mm	Ohms-Ω/Km	in Amps-A	in Amps-A	in Amps-A
1.5	13.700	30	29	24
2.5	8.210	41	39	33
4	5.090	55	52	44
6	3.390	70	67	57
10	1.950	98	93	79
16	1.240	132	125	107
25	0.795	176	167	142
35	0.565	218	207	176
50	0.393	274	260	219
70	0.277	406	386	325
95	0.210	491	467	393
120	0.164	576	547	461
150	0.132	670	637	536
185	0.108	784	745	627
240	0.0817	944	897	755

(Source: https://deekayelectricals.com/polycab-solar-dc-cable/)

AC Cable
Core of AC is determined based on AC-Phase output of inverter
i.e.
1-Phase output – 2 Core AC Cable
3-Phase output – 4 Core AC Cable
Here since our inverter is single core, we should consider
Cu 2C _____ sq.mm. AC Cable

TABLE-4 "POLYCAB" TWO CORE COPPER CONDUCTOR, XLPE INSULATED, UNARMOURED & ARMOURED CABLE CONFORMING TO IS 7098 PART-1/1988

650 / 1100 VOLTS — WEIGHT AND DIMENSIONS

Nominal Size of Conductor	Form of Conductor Circular Shaped	Nominal Thickness of XLPE Insulation	Minimum Thickness of PVC Inner Sheath	Unarmoured Cable: Nominal Thickness of PVC Outer Sheath	Unarmoured Cable: Approx. Overall Diameter of Cable	Unarmoured Cable: Approx. Weight of Cable	Formed Wire/ Strip Armoured Cable: Nominal Dimension of GI Flat Strip	Formed Wire/ Strip Armoured Cable: Minimum Thickness of PVC Outer Sheath	Formed Wire/ Strip Armoured Cable: Approx. Overall Diameter of Cable	Formed Wire/ Strip Armoured Cable: Approx. Weight of Cable	Round Wire Armoured Cable: Nominal Dimension of GI Round Wire	Round Wire Armoured Cable: Minimum Thickness of PVC Outer Sheath	Round Wire Armoured Cable: Approx. Overall Diameter of Cable	Round Wire Armoured Cable: Approx. Weight of Cable	Current Rating: In Ground	Current Rating: In Air	* Normal Delivery Length
Sq.mm.	mm	mm	mm	mm	mm	Kgs./Km	mm	mm	mm	Kgs./Km	mm	mm	mm	Kgs./Km	Amps.	Amps.	Mtrs.
4	Solid	0.7	0.3	1.8	12.5	165	-NA-	-NA-	-NA-	-NA-	1.4	1.24	14.5	480	51	44	1000
4	Stranded	0.7	0.3	1.8	13.0	175	-NA-	-NA-	-NA-	-NA-	1.4	1.24	15.5	525	51	44	1000
6	Solid	0.7	0.3	1.8	13.5	210	-NA-	-NA-	-NA-	-NA-	1.4	1.24	15.5	564	63	56	1000
6	Stranded	0.7	0.3	1.8	14.0	225	-NA-	-NA-	-NA-	-NA-	1.4	1.24	16.5	610	63	56	1000
10	Stranded	0.7	0.3	1.8	16.0	300	-NA-	-NA-	-NA-	-NA-	1.4	1.24	18.0	740	88	75	1000
16	Stranded	0.7	0.3	1.8	14.0	425	-NA-	-NA-	-NA-	-NA-	1.4	1.40	17.0	770	113	98	1000
25	Stranded	0.9	0.3	2.0	17.0	640	4 x 0.8	1.40	18.5	910	1.6	1.40	20.0	1100	144	131	1000
35	Stranded	0.9	0.3	2.0	19.0	840	-do-	1.40	20.0	1025	1.6	1.40	22.0	1350	175	150	1000
50	Stranded	1.0	0.3	2.0	21.0	1120	-do-	1.40	22.5	1435	1.6	1.40	24.0	1670	208	194	1000
70	Stranded	1.1	0.3	2.0	23.0	1540	-do-	1.56	25.5	1910	1.6	1.56	27.0	2200	256	244	1000
95	Stranded	1.1	0.4	2.2	26.5	2075	-do-	1.56	28.0	2475	2.0	1.56	30.5	2925	300	288	500
120	Stranded	1.2	0.4	2.2	28.5	2535	-do-	1.56	30.5	2985	2.0	1.56	33.0	3485	344	331	500
150	Stranded	1.4	0.4	2.2	32.0	3070	-do-	1.72	34.0	3600	2.0	1.72	36.0	4100	388	381	500
185	Stranded	1.6	0.5	2.4	35.5	3800	-do-	1.72	37.0	4490	2.0	1.88	40.0	5040	438	438	500
240	Stranded	1.7	0.5	2.6	39.5	4870	-do-	1.88	41.0	5575	2.5	2.04	45.0	7370	506	512	500
300	Stranded	1.8	0.6	2.8	43.5	6075	-do-	2.04	45.5	6910	2.5	2.20	49.0	9010	562	581	500
400	Stranded	2.0	0.6	3.0	49.0	8050	-do-	2.36	51.0	8950	2.5	2.36	54.4	10250	612	662	500

The above data is approximate and subject to manufacturing tolerance.
* Delivery length tolerance is ±5 %. Length more than normal as per customer request.

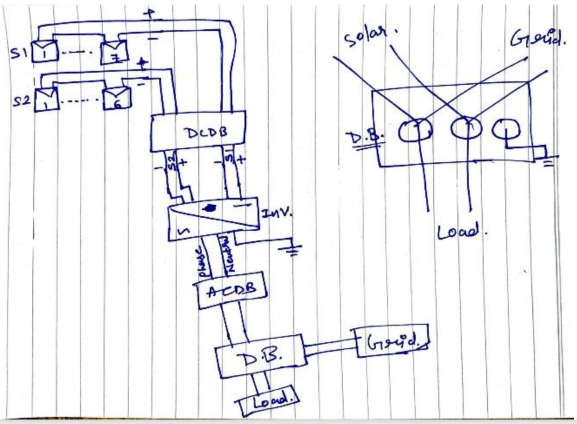
Weight, Dimension data & Current carrying capacity of cables

(Source: https://pdf4pro.com/view/details-make-the-difference-indiancables-net-5b17c3.html)

In above table
Look into column of "Current Ratings".
Look into "In Air"
Find out AC output current of inverter in that column i.e. 19.1A
Keep eye on that raw and look into first column of that corresponding raw.
In our case that Ans is "4"

Hence our AC Cable would be
Cu 2C 4 sq.mm. AC Cable

Step 5: Single Line Diagram



IV. CRITERIA FOR SELECTION OF MODULE

- Cost: What is the rate in terms of Rs. per Watt?
- Power: Range OR Specific?
- Size: (Mono/ Poly-crystalline silicon) 60 OR 72 Cell OR smaller?
- Type: Mono/ Poly-crystalline silicon OR thin-film?
- Bypass Diodes in Junction Box: 3 OR 6 OR 12 OR other?
- IEC Certification available?
- Warranty on Performance and Workmanship available?
- Payment terms: How much advance?
- Delivery time: Readily available or months?
- Reputation and Bankability of Manufacturer

V. CRITERIA FOR SELECTION OF INVERTER

Main Components of PCU

- IGBTs
- Gate Driver Cards
- Snubber Capacitors & Discharge Resistors
- Heat sink with blower fans
- DC Bus Capacitor
- L-C-L Filter
- Grid Synchronizing Contactor
- DC and AC Isolators
- Fuses for DC inputs
- Cabinet and L-C-L filter cooling fans
- Transformer (Only for PCUs with transformer isolation)
- EMI & EMC Filters
- Surge Protection Devices (SPDs)

Important Parameters of PCU

- DC Nominal and Maximum Power
- Efficiency – Maximum and European
- Total Harmonic Distortion (THD)
- MPPT Range
- Aux. power consumption
- Grid voltage and frequency tolerances
- Protection Features
- Ingress Protection (IP) rating
- Operating range of temperature
- Dimensions and Weight
- Remote & Local controlling and monitoring

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