A Case Study for a Single-Phase Inverter PV System for a Three-Bedroom Apartment

Course No: R01-015
Credit: 1 PDH

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Pre-calculations

A. Calculation of sun hours on shortest day:

a) Design for the shortest day, 21/12,

I. azimuth angle = -23.45°,

II. Latitude angle=31°,

III. Altitude angle = 0 and 180 for sunrise and sun set,

IV. Sine (altitude angle) = sine (azimuth angle) * sine (latitude angle) + cosine (azimuth angle) * cosine (latitude angle) * cosine(h)

V. h=15*(t-12)

VI. Sunrise is at 7 am and sunset is at 5 pm,

VII. sun light length is 10 hours per day

OR

b) Use the site mentioned in reference (2)

Mon 2017/12/18:	06:52	10:09 of daylight	17:02
Tue 2017/12/19:	06:53	10:09 of daylight	17:02
Wed 2017/12/20:	06:53	10:09 of daylight	17:03
Thu 2017/12/21:	06:54	10:09 of daylight	17:03
Fri 2017/12/22:	06:54	10:09 of daylight	17:04
Sat 2017/12/23:	06:55	10:09 of daylight	17:04
Sun 2017/12/24:	06:55	10:09 of daylight	17:05

B. Assume that average daily solar radiation satisfies solar panel NMOT datasheet conditions

C. KWH = KW * number of hours (i.e., one KWH = 3.6 MJ)

Average daily load estimation

Load	Average Power Consumption (KW)	Quantity	Average Operation (hours/day)	Average Daily Load (KWH)
Fridge	0.079	1	24	2.090
Mixer	0.300	1	0.5	0.150
Washin g machine	0.500	1	4	2.000
Boiler	0.400	1	1	0.400
Ironer	1.000	1	1	1.000
Pc	0.150	1	12	1.800
TV	0.150	1	8	1.200
55w lamp	0.055	7	12	4.620
55w lamp	0.055	4	4	0.880
Deep freezer	0.300	1	8	2.400
Laptop	0.050	1	12	0.600
Phone Charger	1.500	1	3	4.500
Net router	0.020	1	24	0.480
Total	4.559			22.120

A dynamic factor of 10 % is assigned to the fridge (An increase of 10% is assigned to the daily fridge load to account for the opening and the closing the fridge).

Wiring connections losses are ignored.

Verifying average load calculation by using a screen shot of monthly utility bill

703 KWH monthly consumption is assumed.

Assume a month with a constant daily routine day (i.e., all days have same load pattern)

$$\frac{KWH}{day} = \frac{703}{30} = 23.4\ KWH$$

For the given theoretical energy model of the apartment represented in the table,

$$Error\ due\ to\ ignoring\ wiring\ connection\ losses\ =\ (23.4 - 22.12) * \frac{100}{23.4} = 5.5\ \%$$

$$\frac{Cost}{KWH} = \frac{427}{703} = 0.61\ P.E$$

As an energy saving practice, PC USB ports are used to charge the phone to exclude phone chargers from load calculation since they contribute to a considerable load percent. By applying so, the new average daily load is 17.62 KWH, and the new cost is 0.61*17.62 = 11 L.E/day or 330 L.E/month.

It is also assumed that although loads in summer may vary, they would approximately result in the same average daily consumption as winter (i.e., If fan load increases for cooling purposes, number of lamps decreases as summer day length is longer than winter day length).

Average daily load segmentation

On grid loads (No transition or secondary supplies)

Load	Average Power Consumption (KW)	Quantity	Average Operation (hours/day)	Average Daily Load (KWH)
Ironer	1.000	1	1	1.000
TV	0.150	1	8	1.200
Total	1.150			2.200

1st class emergency Loads (Uninterruptable power supply (UPS) as transition backup, and hybrid inverter as secondary supply, and generator as secondary backup supply)

Load	Average Power Consumption (KW)	Quantity	Average Operation (hours/day)	Average Daily Load (KWH)
Pc	0.150	1	12	1.800
Net router	0.020	1	24	0.480
Total	0.170			2.280

Uninterruptable power supply (UPS) covers transience time between blackout and diesel generator operation (on average 2 minutes)

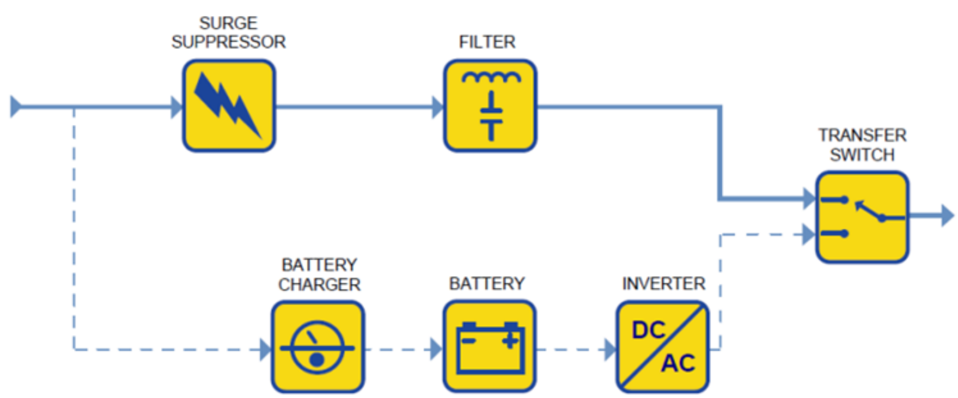


Figure above is UPS schematic

A surge protector (or surge suppressor or surge diverter) is an appliance or device designed to protect electrical devices from voltage spikes. A surge protector attempts to limit the voltage supplied to an electric device by either blocking or shorting to ground any unwanted voltages above a safe threshold.

2nd class emergency Loads (Hybrid inverter as secondary supply, and generator as secondary backup supply)

Load	Average Power Consumption (KW)	Quantity	Average Operation (hours/day)	Average Daily Load (KWH)
Fridge	0.079	1	24	2.090
Mixer	0.300	1	0.5	0.150
Washing machine	0.500	1	4	2.000
Boiler	0.400	1	1	0.400
55w lamp	0.055	7	12	4.620
55w lamp	0.055	4	4	0.880
Deep freezer	0.300	1	8	2.400
Laptop	0.050	1	12	0.600
Total	1.739			13.140

System equipment selection

A common selection criterion is operating conditions at the ambient temperature, or, in case operating conditions are not dependent on ambient temperature in the data sheet and constant over a given temperature range, use the rated operating conditions.

Selection criteria are:

a) rated input/output (I/O), DC/AC, currents
b) rated input/output (I/O), DC/AC, voltages
c) nominal KVA/KW (For residential applications, a power factor of 1 is assumed)
d) Total harmonic distortion (recommended values 1% to 6%) – For UPS and hybrid inverter
e) step load at startup (percent from rated load) – For UPS and hybrid inverter

UPS for 1st class emergency loads

Product 300 Watt Pure Sine Wave UPS Inverter | inverter.com is selected.

From datasheet, power rating = 300 W, input DC voltage = 12 V, input DC current = 20 A

Power consumption at peak load = 170 W

$$input\ ampere\ at\ peak\ load$$

$$= \frac{peak\ load\ power}{Inverter\ efficiency * Input\ voltage * Transformer\ efficiecy}$$

$$= \frac{170}{0.95 * 12 * 0.9} = 16.6\ A < 20\ A$$

Expected cost before taxes and shipping = 1 * $234.15

UPS battery

$$total\ average\ KWH\ of\ 1st\ class\ emergency = 2.28\ KWH$$

$$battery\ ampere\ hour$$

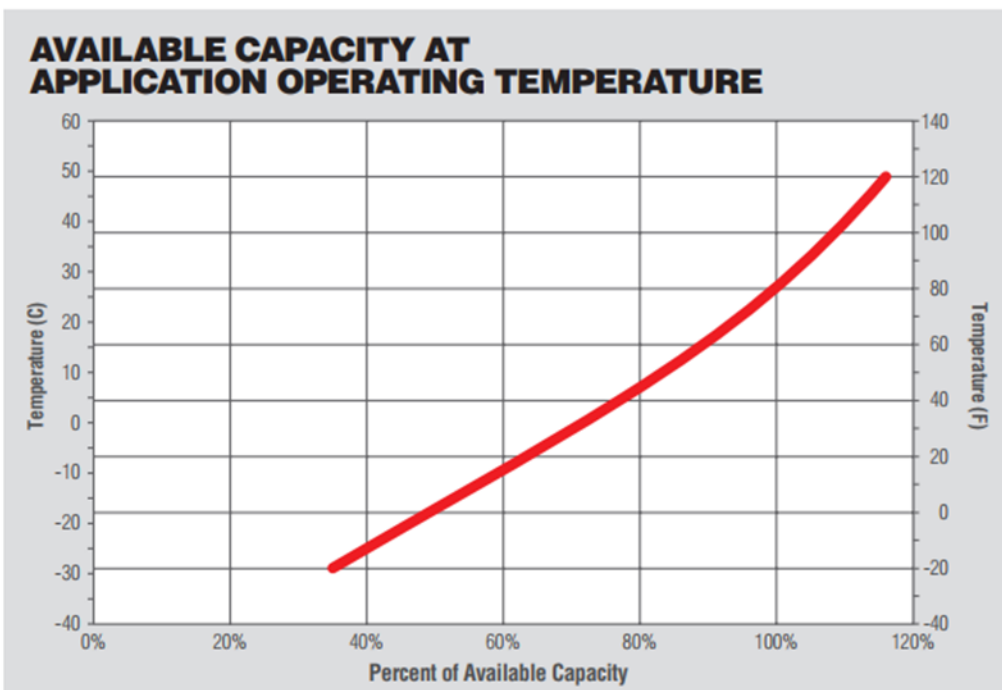
$$= \frac{average\ WH * number\ of\ consecutive\ cloudy\ weather\ days * temprature\ factor}{Battery\ voltage * battery\ depth\ of\ discharge\ factor}$$

$$= \frac{2.28 * 1000}{12} = 190\ AH$$

2 batteries in parallel of type Duracell Ultra 12V 100AH Deep Cycle AGM SLA Battery with P Terminals - WKDC12-100P at Batteries Plus are used to obtain needed AH.

Expected price before taxes and shipping = 2 * $274.99

Battery depth of discharge factor resembles charge percent to be kept in the battery for normal operation consumption to prevent battery dead case



From figure above, it is shown that temperature affects battery available capacity, the same applies to UPS performance. That's why UPS is kept in air-conditioned room, to keep it at the datasheet recommended operating condition (Temperature) that would result in desired performance.

Hybrid inverter selection:

For hybrid (off-grid plus grid-tie functionality) inverter:

$$hybrid\ inverter\ average\ peak\ load\ power = 0.17 + 1.739 = 1.909\ KW$$

Demand factor and safety factor are assumed to cancel out and peak demand is used.

Product GS4048A-01 4,000W 48V - Unbound Solar is used as a reference for calculations and selection

From data sheet, continuous DC input current = not given = 4000 / 48 = 83.3 A, DC input voltage = 48 V, AC grid input current = 50 A, AC output current = 16.7 A

To estimate continuous DC input current, a correlation is made based on datasheet Conext XW PRO 6848 6,800W 48V - Unbound Solar where DC input current is given.

AC input ampere at peak load = AC output ampere at peak load

$$= \frac{peak\ load\ power}{Input\ voltage} = \frac{1.909 * 1000}{220} = 8.7\ A < 57.5\ A\ and < 16.7\ A$$

DC input ampere at peak load

$$= \frac{peak\ load\ power}{Inverter\ efficiency * Input\ voltage * Transformer\ efficiecy}$$

$$= \frac{1.909 * 1000}{0.95 * 48 * 0.9} = 46.6\ A < 83.3\ A$$

number of inverters batteries = number of charge controllers

Charge controllers are selected based on rated inverter charging DC current and battery voltage. However, since hybrid inverters include a charger, no selection is made for this part.

Expected price before taxes and shipping = number of inverters * cost per inverter = 1 * 3004.54

Hybrid inverter batteries

$$average\ KWH\ of\ 1st\ and\ 2nd\ class\ emergency\ loads = 2.28 + 13.14 = 15.42\ KWH$$

$$battery\ ampere\ hour$$

$$= \frac{average\ WH * number\ of\ consecutive\ cloudy\ weather\ days * temprature\ factor}{Battery\ voltage * battery\ depth\ of\ discharge\ factor}$$

$$= \frac{15.42 * 1000}{24} = 322\ AH$$

2 batteries in parallel of type 48V POLAR BEAR ELITE - NMC - 200Ah - 10kWh - BigBattery.com are used to obtain needed AH.

Expected price before taxes and shipping = 2 * 3750

Hybrid inverter Batteries may be omitted or partially obtained for budget constraints since the system has a UPS to cover the transience period of 1^{st} class emergency loads. Inverter batteries are intended for the hybrid inverter to acts a backup secondary supply along with the generator.

Solar panels selection based on daily average load:

$$solar\ peak\ load\ power = hybrid\ inverter\ average\ peak\ load\ power = 1.909\ KW$$

DC voltage of hybrid inverter input (40 to 60 VDC) and solar panel output (open circuit voltage 46.88 V) are compatible. In case of a drop in solar panel output voltage to a value less than the open circuit voltage (for example, V_NMOT), hybrid inverter embedded charger steps up/down the solar panel voltage for it to match battery and inverter voltages.

Astronergy 415 watt Module Silver Mono CHSM72M-HC - 35mm Frame 1500V - Unbound Solar has NMOT power of 308.5 W

Number of solar panels in series = solar peak load power / power per solar panel at NMOT = 1.909 * 1000 / 308.5 = 7

Expected price before taxes and shipping = 7 * $299

Generator selection

$$Generator\ load\ power = hybrid\ inverter\ average\ peak\ load\ power = 1.909\ KW$$

WEN DF475T Dual Fuel 120V/240V Portable Generator with Electric Start Transfer Switch Ready, 4750-Watt, CARB Compliant : Everything Else datasheet indicates that it runs 11 hours at half load (4750 / 2 = 2375 W)

Expected price before taxes and shipping = 1 * $379.99

Economics

$$Expected\ cost\ without\ inveter\ batteries\ or\ generator\ = 5881.67 * 3 = \$17645.01$$

$$Expected\ cost\ without\ inveter\ batteries\ = 6261.66 * 3 = \$18784.98$$

This is used for payback estimation

$$Expected\ cost\ with\ 48\%\ partial\ load\ capacity\ batteries\ = 10011.66 * 3 = \$30034.98$$

$$Expected\ cost = 13761.66 * 3 = \$41284.98$$

3 multiplier is for taxes, shipping, installation, contractor profit and scheduled maintenance

To calculate payback period, assume:

- No black out
- Minimum daily solar radiation satisfies panel NMOT datasheet conditions
- Minimum Sun hours of 10 hours per day year round
- No change in KWH cost
- loads are steady state (periodic everyday)
- Power consumption during night equals the excess in power earned by solar panels during daylight (i.e., PV panels earned power covers daily and night loads)
- Grid charging and crediting policy has the same value per KWH (i.e., no running cost, only initial cost is accounted)

$$estimated\ payback\ period$$

$$= \frac{total\ cost}{price\ perKWH\ per\ day * solar\ saving * 360\ days} = \frac{18784.98 * 6}{0.61 * 17.62 * 365} = 29\ years$$

Since selected system accommodates 120 V and 220 V,

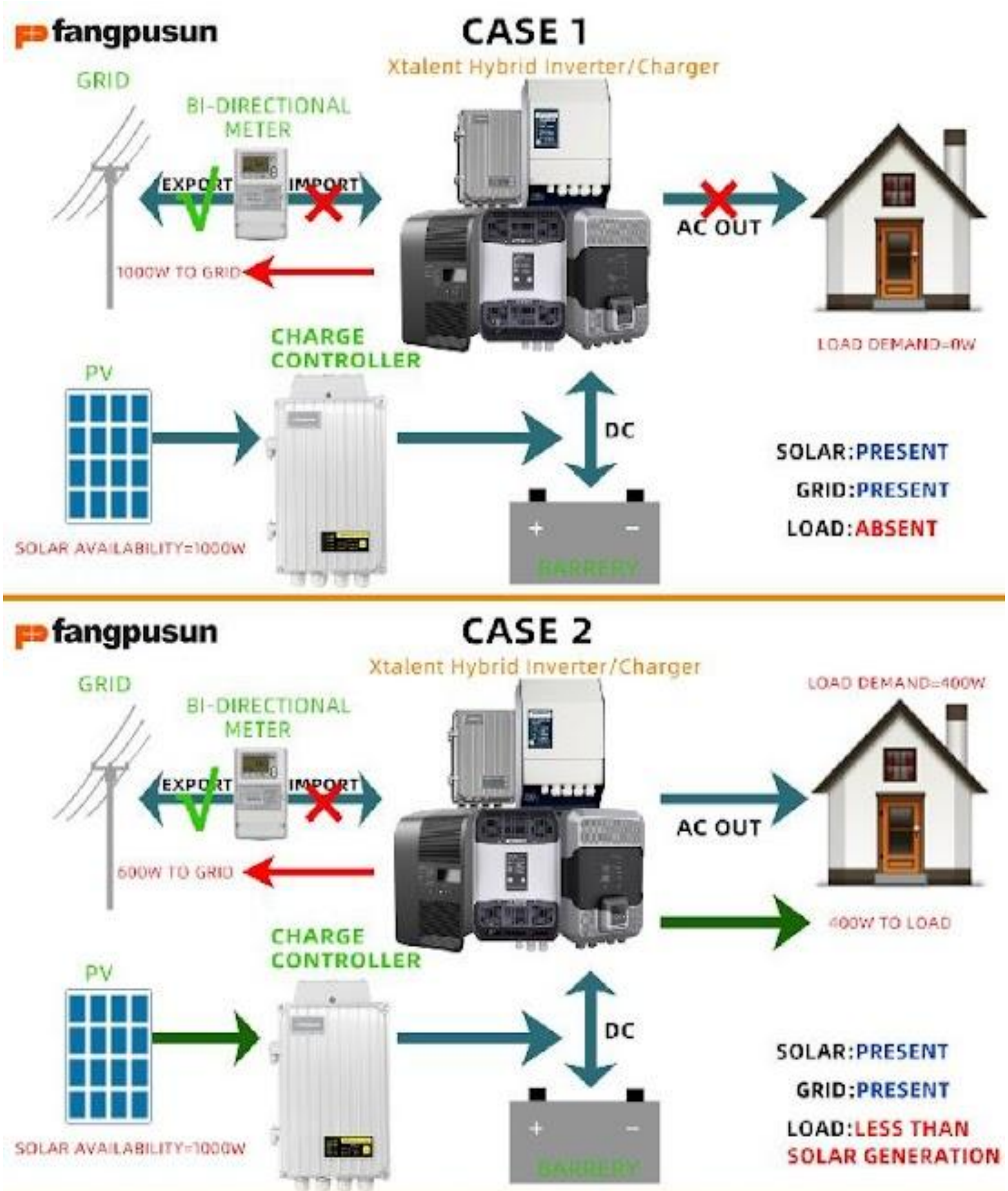
$$estimated\ payback\ period\ in\ Ohio, USA\ = \frac{27198.39}{0.12 * 17.62 * 365} = 21\ years$$

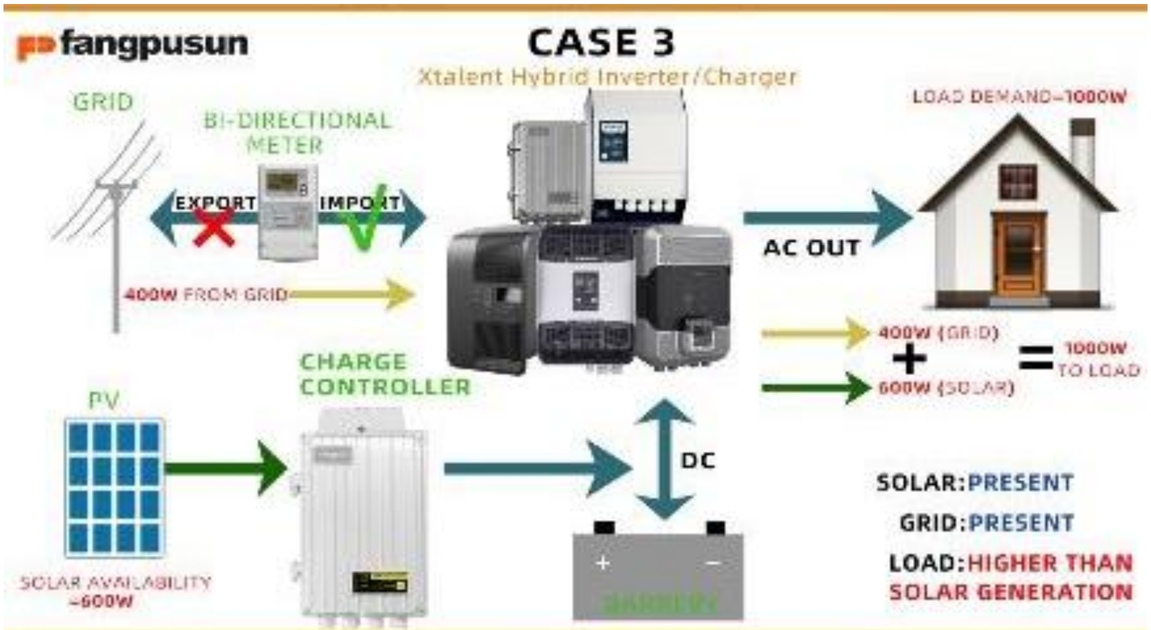
Based on estimated cost analysis, this project is not applicable for short term residence.

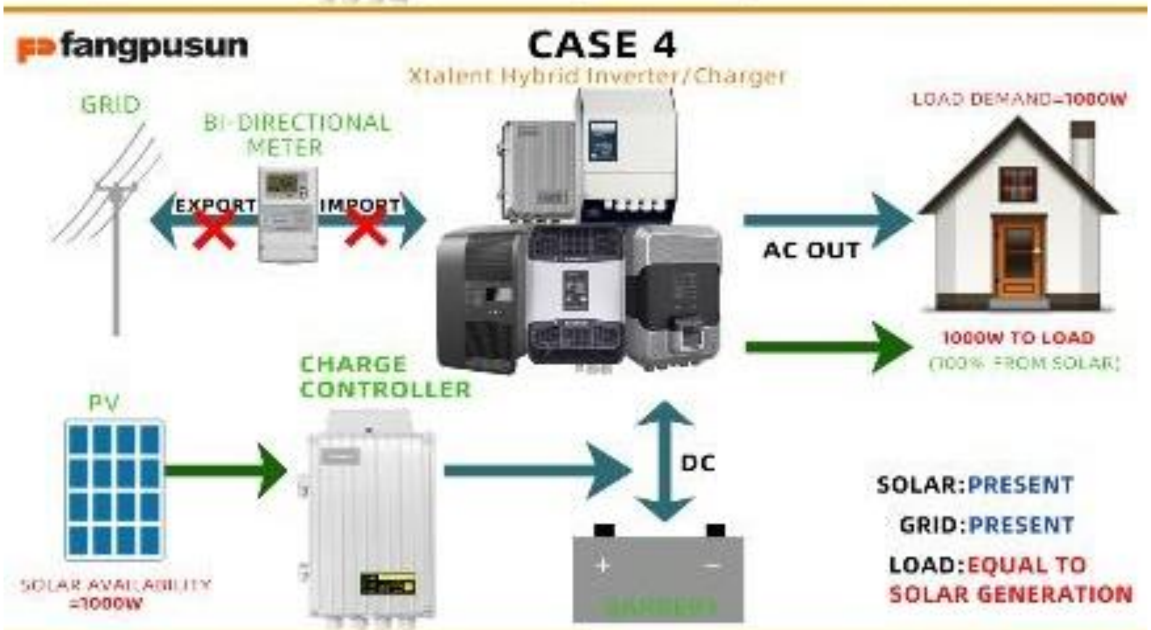
This project can be considered for long-term residence.

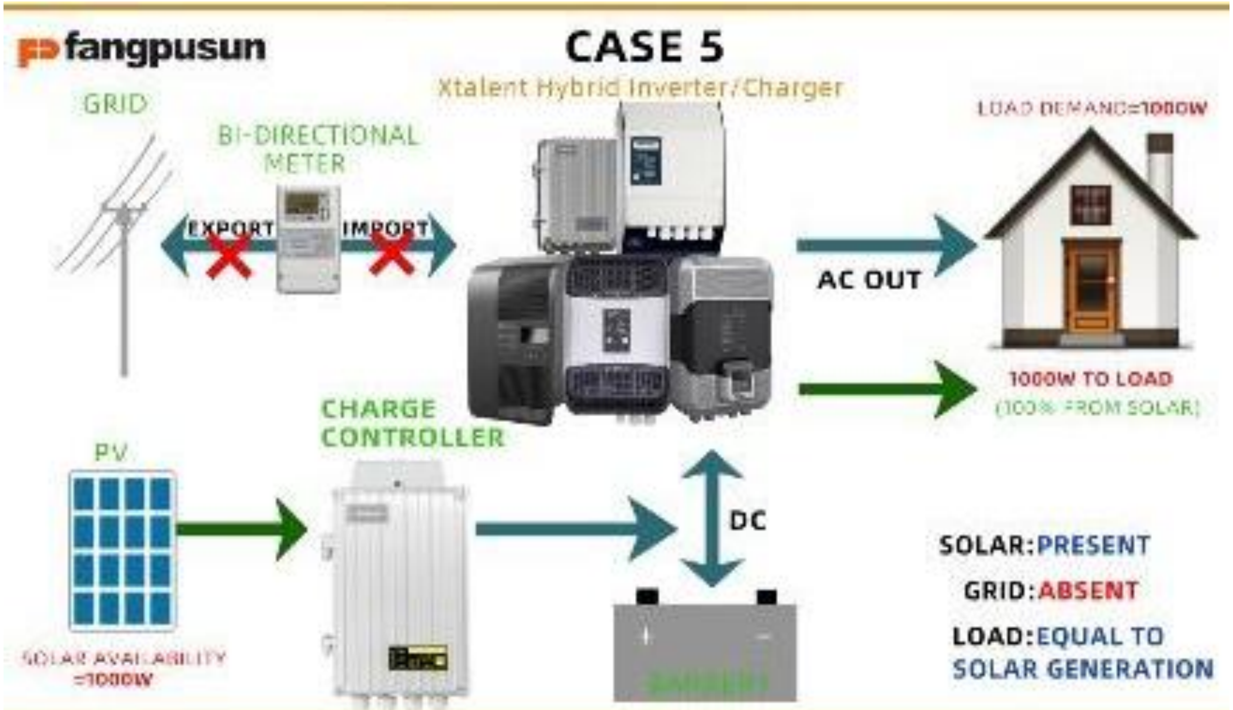
Schematics of system operation

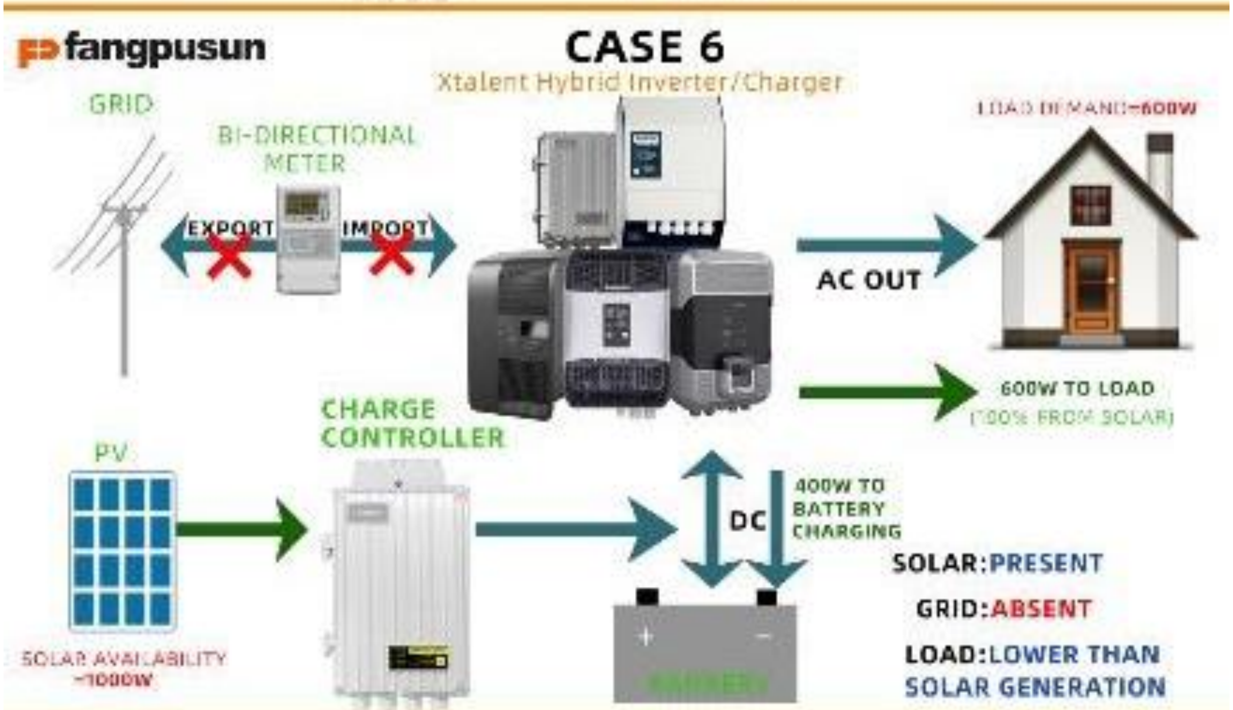
The following four figures below are for cases representing some of the scenarios a PV system encounters during operation. Reference: P_Fangpusun




fangpusun
CASE 3
Xtalent Hybrid Inverter/Charger
GRID
BI-DIRECTIONAL METER
EXPORT
IMPORT
400W FROM GRID
LOAD DEMAND=1000W
AC OUT
400W (GRID)
+
600W (SOLAR)
=
1000W TO LOAD
CHARGE CONTROLLER
PV
DC
SOLAR AVAILABILITY =600W
SOLAR:PRESENT
GRID:PRESENT
LOAD:HIGHER THAN SOLAR GENERATION


fangpusun
CASE 4
Xtalent Hybrid Inverter/Charger
GRID
BI-DIRECTIONAL METER
EXPORT
IMPORT
LOAD DEMAND=1000W
AC OUT
1000W TO LOAD
(100% FROM SOLAR)
CHARGE CONTROLLER
PV
DC
SOLAR AVAILABILITY =1000W
SOLAR:PRESENT
GRID:PRESENT
LOAD:EQUAL TO SOLAR GENERATION


fangpusun
CASE 5
Xtalent Hybrid Inverter/Charger
GRID
BI-DIRECTIONAL METER
EXPORT
IMPORT
AC OUT
LOAD DEMAND=1000W
1000W TO LOAD
(100% FROM SOLAR)
CHARGE CONTROLLER
PV
DC
SOLAR AVAILABILITY =1000W
SOLAR:PRESENT
GRID:ABSENT
LOAD:EQUAL TO SOLAR GENERATION


fangpusun
CASE 6
Xtalent Hybrid Inverter/Charger
GRID
BI-DIRECTIONAL METER
EXPORT
IMPORT
AC OUT
LOAD DEMAND=600W
600W TO LOAD
(100% FROM SOLAR)
CHARGE CONTROLLER
PV
DC
400W TO BATTERY CHARGING
SOLAR AVAILABILITY =1000W
SOLAR:PRESENT
GRID:ABSENT
LOAD:LOWER THAN SOLAR GENERATION

Two Figures below are comparison between on grid and off grid PV system operation modes. Reference: Aurora Power & Design.

References

1) Average load calculations: home devices data sheet
   solardirect.com/pv/systems/gts/gts-sizing-power.html

2) sun hours per day:
   jan.moesen.nu/daylight-calculator/?location=Alexandria+Governorate%2C+Egypt&latitude=30.7622959&longitude=29.69626770000002

3) battery calculations:
   solardirect.com/pv/systems/gts/gts-sizing-battery.html

4) solar panel calculations:
   solardirect.com/pv/systems/gts/gts-sizing-array.html

5) solar panel selection:
   wholesalesolar.com/solar-panels#hyundai