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RESEARCH ARTICLE

ENERGY PROBLEMATIC OF THE POWER FACTOR IN SOLAR INSTALLATIONS: CASE STUDIES, HIGHLIGHTING AND PROPOSED SOLUTIONS

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ABSTRACT

The aim of this article is to highlight the consumption of reactive energy and the consequences of not taking it into account in solar installations. Unlike active power, it is responsible for the magnetization or induction of electrical circuits (enabling the transfer of active power) and remains constant (depending on the type of equipment).The consumption of reactive energy is closely linked to the power factor which for certain installations takes on significant values. If for some equipment such as lighting, this energy is negligible or even zero, this is not the case for others used for comfort (fans, refrigerators, etc.) where its proportion is significant. For the occasion, we based our experimental study by considering the measurements of electrical quantities (power, currents and derived parameters) of a photovoltaic solar installation of an individual in Ouagadougou. These parameters were measured through computer supervision tools of said installation. From this study it emerged that reactive power can occupy up to 50% of the total apparent power. In a photovoltaic solar installation, this energy is provided by solar panels or batteries and its failure to be taken into account during dimensioning leads to premature aging of the batteries which also represent a gigantic proportion in the budgetary cost. There are also system malfunctions during significant power calls. In order to avoid these inconveniences, our study recommends taking reactive energy into account in solar sizing or providing reactive energy compensation.

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INTRODUCTION

Photovoltaic solar energy is present in the energy flow of Burkina Faso, even if its contribution remains low (4.8 ktep for less than 1% in 2018) [1]. It is used independently in services and homes because of very recurrent power cuts and the isolation of some from electrical distribution centers. However, this energy satisfaction is often short-lived because the storage batteries struggle to cover their expected lifespan. Without having statistics of the installations suffering from this anomaly, this study aims to elucidate the causes of this problem by excluding the primary parameters concerning the quality of the material and the effect of temperature. Our work will then be a case study on an isolated autonomous PV site in Ouagadougou with the hypothesis of finding other parameters not taken into account during the sizing.

CONTEXTS AND ISSUES

Electrical equipment consumes two energies which are active energy (Ep) and reactive energy (Eq) deriving respectively from active power (P) and reactive power (Q).

If active power is the convertible and variable electrical quantity (depending on the type of equipment and conversion), reactive power is responsible for the magnetization or induction of electrical circuits (allowing the transfer of energy) and remains constant by equipment.

However, in installations with inductive loads (fans, motors, refrigerators, air conditioners, etc.), reactive energy represents a good proportion of the total power [2].

These powers are represented in Figure 1

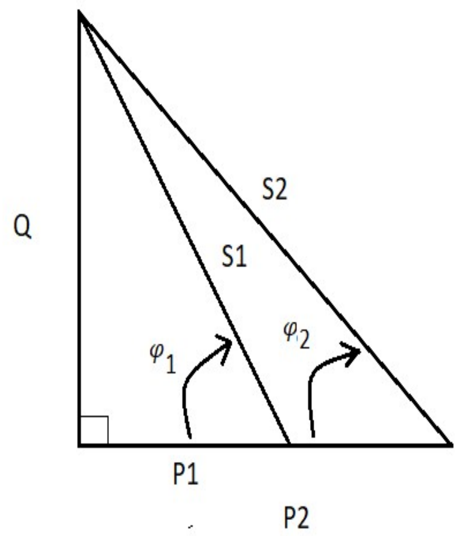


Figure1. Triangle of powers

We derive the following relationships:

$$S = \sqrt{P^2 + Q^2} \quad \text{(equation 1)}$$

$$P = S * \cos\varphi \quad \text{(equation 2)}$$

$$Q = S * \sin\varphi \quad \text{(equation 3)}$$

$$Q = P\tan\varphi \quad \text{(equation 4)}$$

With $\cos\varphi$: power factor

φ: time difference between voltage and current.

In the same equipment, the active power can vary according to the load while the reactive power remains constant

From these relations:
If the power factor ($\cos\varphi$) →1 ; then the reactive power Q →0 ; and P=S .
If the power factor ($\cos\varphi$) →0 ; then the active power P →0 and Q=S .
If the power factor ($\cos\varphi$) is average, then the reactive power Q and the active power P are in non-negligible proportions in S.
Inductive equipment with high active power has a better power factor (close to 1) while it is poor (≈ 0.5) for low active powers [2]

However, in photovoltaic solar dimensions (solar panels and batteries), only active energy is taken into account.

For N electrical equipments with active powers and respective daily electrical consumptions (E_1, E_2, E_3, …, E_n) and (P_{a1}, P_{a2}, P_{a3},…..Pan), the total energy is:

$$E_T\left(\frac{Wh}{j}\right) = \sum_{i=1}^{N} E_i \quad [3] \quad \text{(equation 5)}$$

$$E_i = P_{ai} * t_i$$

P_{ai} = Active power of equipment i

t_i= Average daily operating time of equipment i

The solar peak power is: $P_c = \frac{E_T}{h_i * k_1 * k_2}$ [3] (equation 6)

h_i : average daily sunshine value of the site, Hi, in kWh/m². Day
k_1 : overall efficiency of the installation (0.55 to 0.65)

k_2 : solar panel efficiency taking into account the uncertainty related to orientation and inclination, as well as wear, ...: it is generally estimated at 0.9
The battery capacity is:

$$C_b(Ah) = \frac{E_T * AUT}{U * DOD * \gamma_b} \quad [3] \qquad \text{(equation 7)}$$

$AUT\ (j)$: Storage autonomy
$U\ (Volts)$: Battery voltage
$DOD(\%)$: Battery discharge percentage (Depth Of Discharge).
γ_b : battery performance

In these last three expressions, only the active power is taken into account but in reality the solar source (PV or battery) will also provide the reactive part (not taken into account) of the Energy. However, in domestic installations, common equipments with significant power are fans ($\cos\varphi = 0.5$); refrigerators ($\cos\varphi = 0.6$), air conditioners ($\cos\varphi = 0.7$) [2]. They are also widely used for thermal comfort and food preservation. For example for a 75 W fan, the solar source will provide 150 VA, so in the sizing, only 75 W are taken into account. If the supply voltage is 230 V, the source will supply 652.1 mA instead of 326 mA.

It is the highlighting and the impact of the supply of this reactive energy (not considered) by the photovoltaic solar energy source which will be the subject of our study

REMINDERS OF THE BASIC COMPONENTS ON EQUIVALENT MODELS

Electrical equipment has equivalent models based on the association of basic elements: resistance, capacitance, inductance.
The electronic association of these three elements defines two types of power: active power consumed by the resistance and reactive power supplied or consumed by the capacitance or inductance. Reactive energy is responsible for the magnetization of electrical circuits, thus allowing the conversion of electrical energy into mechanical energy.

Fluorescent lighting: Fluorescent lamps are equipped with ballasts, the model of which is as follows (Figure 2):

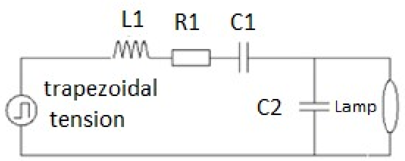


Figure 2. Modeled fluorescent lamp [4]

The parameters are:

L1= 1.5 mH: series indusctance of the ballast
R1 =10 Ω series resistance of the ballast
C1 =100nF: series capacitance of the ballast
C2 = 12 nF: parallel capacitance of the ballast

The power factor of these lamps ranges from 0.82 to 0.95 [2].

Heating element (oven and companies):

The heating elements have the following model (figure 3):

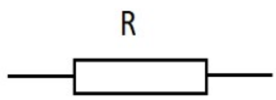


Figure 3. Electric heating element model

The resistance R converts electrical power into heat. Its power factor is 1.

LED lighting element:

LED lamps have the following model (figure 4):

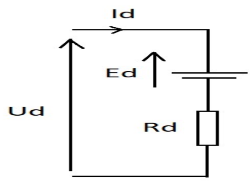


Figure 4. Led lighting element model

The parameters are:

R_d: The internal resistance of the LED.
E_d: The threshold voltage of the LED.

Rotating element (engine and company):

The rotating elements (motors) have the following model (figure 5) :

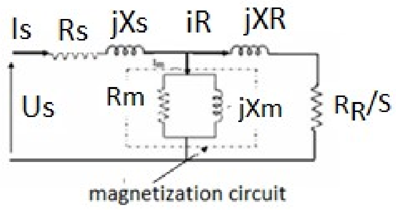


Figure 5. Rotating element model [5]

The parameters are:

R_s: the resistance of a stator phase of the motor
X_s: leakage reactance of a stator phase
R_m: the magnetization resistance
X_m: the magnetization reactance
X_R: the leakage reactance of a rotor phase
R_R: resistance of a rotor phase

Magnetizationallows the conversion of electrical power intomechanical power. Their power factor varies from 0.5 (smallmotor) to 0.9 (large motor) [2].

METHODS

For our experiment, we used technical data from a solar installation at a particular site in Ouagadougou.

PRESENTATION OF THE SITE:

The solar field is composed of 5 strings of solar panels (figure 6):

- 4 strings of 7 panels of 275 W in series
- 2 strings of 3 panels of 265 W in series

Figure 6. Solar fields

The panels are connected to 3 Victron MPPT regulators:

- Two 250/100 regulators which each receive 2 strings of 7 panels of 275W in series
- A 150/85 regulator which receives 2 strings of 3 panels of 265W in series

The outputs of the regulators are connected to a DC busbar with a nominal voltage of 48V. From this DC bus, 2 Victron converters of 5000VA/48V are connected (in parallel configuration).

There is also

- The CERBO GX for communication between the different elements and web communication,
- The BMW 700 for measuring the busbar current,
- The BYD BMS, the communication interface with the battery,
- The fleet of 3 lithium batteries (BYD Flex Lite) of 5 kWh each.

All of these elements are represented in Figures 7 and 8.

Figure 1. Solar electrical panel of site

Figure 8. Lithium battery park of site

Functional and hardware configurations:

From a functional and hardware point of view, the system has the following configurations: (figure 9)

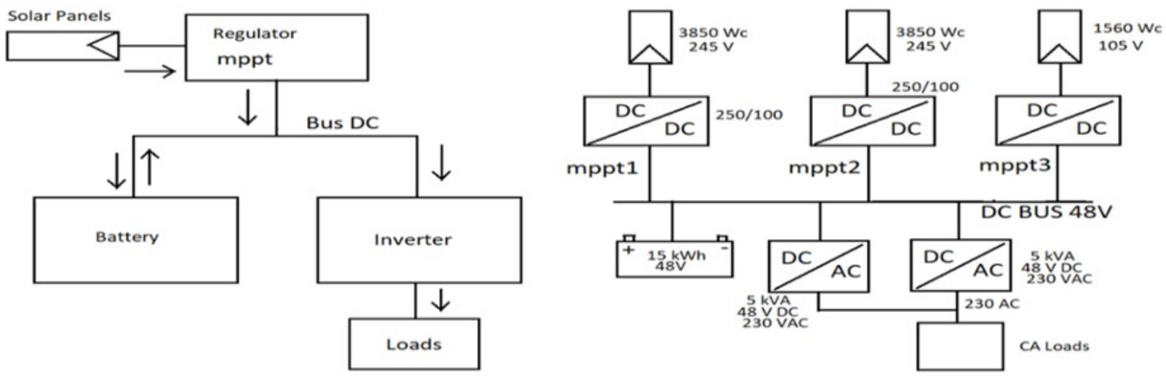


Figure 2. Hardware and functional configuration

From this configuration we derive the following general characteristics (Table 1):

Table 1. Electrical Characteristics

Total solar field	9260 Wc
Installed storage capacity	15 000 Wh (293,1 Ah- 51,2 V)
Inverter Power	10 kVA

Overview of AC Loads:

The Ac loads consist mainly of:

- Three Dakin 1.5 HP Inverter split air conditioners
- One 1 HP water pressure booster
- Two Freezers
- Twelve fans
- Video surveillance system
- Lighting

Victron Energy Remote Monitoring (VRM):

VRM (Victron Remote Monitoring) is the web link between a physical Victron installation and the Internet. [6]
It allows the end user to monitor and access the electrical parameters of the installations.

Monitoring window:

Through the VRM, we have access to the measurements instances of the electrical parameters of the installation which are:

- The solar power of each MPPT regulator and the total solar power
- The currents and voltages of each regulator
- The active power consumed (of the loads)
- The alternating output voltage and its frequency
- The current of the loads
- The charge/discharge power of the battery
- The current and voltage of the battery
- The state of charge of the battery (SOC)
- The temperature of the battery
- The time and the state of the system

Figure 10 shows all of these measurement parameters (in French).

Figure 3. Installation monitoring window on 25 August 2024 on 09: 19 Am

Equations of the system: The system is made up of 3 MPPT regulators, i.e(u_{r1}, i_{r1}) ; (u_{r2}, i_{r2}) ; (u_{r3}, i_{r3}) the instantaneous values of MPPT1, MPPT2, MPPT3. The total instantaneous power delivered by all three regulators is:

$$P_r = \sum_{j=1}^{3} ur_j * ir_j \qquad \text{(equation 8)}$$

For the lithium battery park with a voltage u_b and a current (+i_b in charge) or (-i_b in discharge), its power is:

$$P_b = \pm u_b * i_b \qquad \text{(equation 9)}$$

Pb is positive for a charge and negative for a discharge. The loads connected to the inverter output consume a current ic at a voltage Uc of 230V. The powers consumed are then:

Apparent power: $S_c = u_c * i_c$ (equation 10)

Active power: $P_c = u_c * i_c * \cos\varphi$ (equation 11)

Reactive power: $Q_c = u_c * i_c * \sin\varphi$ or $Q_c = P_c * \tan\varphi$ (equation 13)

We will note the power losses of the MPPT regulators P_1 and those of the converter P_2.

According to the technical data sheets, P_1 is estimated at 2% of the converted power [7] while P_2 is estimated at 5% [8].

These losses are mainly due to the switching of power transistors inside these devices [9].

All of these powers allow us to establish the following electrical power transmission tree (figure 11):

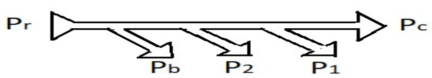


Figure 4. Power shaft

Then $P_c = P_r - P_1 - P_b - P_2$ (equation 14)

It should be noted that we did not consider the power losses in the cables because we measured the powers from the output of the MPPT regulators. In any case, they can be minimized by correctly sizing the cables connecting the PV modules to the MPPT regulators [10]. The same applies to the electrochemical efficiency of the lithium battery [11] where we measure the input/output parameters for a charge/discharge.

RESULTS AND DISCUSSION

Using the VRM, we performed thirty (30) measurements on November 16, 2024 according to 3 system states:

- without charging power from 00:06 to 00:15 (10 samples),
- with charging power and battery not full from 09:43 to 09:49 (10 samples),
- with charging power and battery full from 12:00 to 12:09 (10 samples).

These measurement samples can be found in Tables 2, 3 and 4.

Operations: From these measurement tables (2,3,4) we can deduce the useful parameters of energy conversion, namely:

Table 2. Without charging power from 00:06 to 00:15

N°	PV				Battery				LOADS CA				Time and date
	MPPT1	MPPT2	MPPT3	P_{rt} (W)									
	P_{r1}(W)	P_{r2}(W)	P_{r3}(W)		SOC (%)	U_b (V)	I_b(A)	P_b (W)	U_c(V)	I_c(A)	P_c (W)	S_c(VA)	
1	0	0	0	0	69	53	-13.21	-700	230,3	3	544	690,9	2024-11-16 00:06:47
2	0	0	0	0	69	52,9	-18,7	-989	229,9	4,4	866	1011,56	2024-11-16 00:07:48
3	0	0	0	0	69	52,9	-15,1	-798	229,9	4,6	855	1057,54	2024-11-16 00:08:47
4	0	0	0	0	69	52,9	-14,9	-788	230,6	4,4	842	1014,64	2024-11-16 00:09:47
5	0	0	0	0	69	52,7	-41,5	-2187	229,9	9,2	1952	2115,08	2024-11-16 00:10:47
6	0	0	0	0	69	52,7	-41,3	-2176	229,9	9	1956	2069,1	2024-11-16 00:11:48
7	0	0	0	0	68	52,5	-48,4	-2541	229,9	9	1951	2069,1	2024-11-16 00:12:47
8	0	0	0	0	68	52,8	-12	-633	230,3	3	538	690,9	2024-11-16 00:13:48
9	0	0	0	0	68	52,9	-11,7	-618	229,9	2,9	521	666,71	2024-11-16 00:14:47
10	0	0	0	0	68	52,9	-11,6	-613	230,3	2,9	519	667,87	2024-11-16 00:15:47

Table 3. With charging power and battery not full from 09:43 to 09:49

N°	PV				Battery				LOADS CA				Time and date
	MPPT1	MPPT2	MPPT3	P_{rt} (W)									
	P_{r1}(W)	P_{r2}(W)	P_{r3}(W)		SOC (%)	U_b (V)	I_b(A)	P_b (W)	U_c(V)	I_c(A)	P_c (W)	S_c(VA)	
1	33	2086	2061	4180	69	53,8	61,8	3324,84	229,9	3,9	667	896,61	2024-11-16 09:43:49
2	60	2080	2061	4201	69	53,8	61,2	3292,56	230,3	3,9	718	898,17	2024-11-16 09:44:49
3	65	2085	2055	4205	69	53,8	60,8	3271,04	230,3	3,9	730	898,17	2024-11-16 09:45:49
4	65	2085	2055	4205	69	53,8	60,8	3271,04	230,3	3,9	730	898,17	2024-11-16 09:46:49
5	65	2099	2069	4233	70	53,8	55,3	2975,14	229,9	5,6	1009	1287,44	2024-11-16 09:47:49
6	60	2096	2060	4216	70	53,9	60,1	3239,39	229,9	4,3	800	988,57	2024-11-16 09:48:50
7	60	2118	2082	4260	71	53,8	60,1	3233,38	229,5	4,4	820	1009,8	2024-11-16 09:49:49
8	60	2129	2082	4271	71	53,8	58,3	3136,54	230,3	4,4	824	1013,32	2024-11-16 09:50:50
9	65	2146	2082	4293	71	53,8	61	3281,8	230,3	4,4	829	1013,32	2024-11-16 09:51:49
10	65	2152	2082	4299	72	53,8	61,5	3308,7	229,9	4,4	838	1011,56	2024-11-16 09:52:49

Table 4. With charging power and full battery from 12:00 to 12:09

N°	PV				Battery				LOADS CA				Time and date
	MPPT1	MPPT2	MPPT3	P_{rt} (W)									
	P_{r1}(W)	P_{r2}(W)	P_{r3}(W)		SOC (%)	U_b (V)	I_b(A)	P_b (W)	U_c(V)	I_c(A)	P_c (W)	S_c(VA)	
1	0	1439	2302	3741	100	-3,5	54,6	-202	229,9	17,1	3405	3931,29	2024-11-16 12:00:49
2	0	1455	2345	3800	100	-0,6	54,6	-32	229,9	17,1	3385	3931,29	2024-11-16 12:01:49
3	0	1477	2378	3855	100	-2,1	54,7	-114	230,3	16,9	3387	3892,07	2024-11-16 12:02:49
4	0	1466	2466	3932	100	-0,5	54,7	-92	230,3	17,1	3407	3938,13	2024-11-16 12:03:50
5	0	621	1891	2512	100	2,4	54,7	98	230,3	10,4	1946	2395,12	2024-11-16 12:04:49
6	0	626	1864	2490	100	1,5	54,7	60	230,3	10,6	1984	2441,18	2024-11-16 12:05:49
7	0	637	1832	2469	100	0,4	54,7	21	229,9	10,4	1952	2390,96	2024-11-16 12:06:49
8	0	648	1799	2447	100	1,4	54,7	76	229,9	10,9	1979	2505,91	2024-11-16 12:07:50
9	0	692	1761	2453	100	2,6	54,7	131	229,9	10,7	1975	2459,93	2024-11-16 12:08:49
10	0	725	1729	2454	100	1,1	54,7	60	230,3	10,6	1968	2441,18	2024-11-16 12:09:49

P_{r1}: the useful power of the MPPT1 regulator
P_{r2}: the useful power of the MPPT2 regulator
P_{r3}: the useful power of the MPPT3 regulator
Prt: the total power supplied by the regulators.
P_{cc}: the total direct current power available on the 48V busbar
P_b: the power supplied by the batteries
P_c: the active power of the loads
Q_c: the reactive power of the loads

S_c: the apparent power of the loads
P_2: the power losses in the converter
PF: the power factor
R: the efficiency
P_{ccu}: the useful power of the 48V Bus

We have :

$$P_{rt} = P_{r1} + P_{r2} + P_{r3} \quad \text{(equation 15)}$$

$$P_{cc} = P_{RT} - P_b \quad \text{(equation 16)}$$

$$P_2 = 0.05 * P_c \quad \text{(equation 17)}$$

$$P_{ccu} = P_{cc} - P_2 \quad \text{(equation 18)}$$

$$PF = \frac{P_c}{S_c} = \cos\varphi \quad \text{(equation 19)}$$

$$R = \frac{S_c}{P_{ccu}} \quad \text{(equation 20)}$$

$$Q_c = \sqrt{S_C - P_c} \quad \text{(equation 21)}$$

Applying these relationships gives us the following tables 5, 6 and 7:

Table 5. Exploitation of measurements 00h06 min to 00h15 min

N°	PV	BATTERY	DC BUS POWER	AC CHARGE POWER		Loss P_2	$P_{ccu}= P_{cc} - P_2$	PF	YIELD $S_c/(P_{ccu})$	Q_c (VAR)
	Prt (W)	Pb(W)	Pcc= Prt -Pb (W)	P_c (W)	S_c(VA)	Loss P_2 =0,05 *P_c	$P_{cc} - P_2$			
1	0	-700	700	544	690,9	27,2	672,8	0,79	0,95	425,91
2	0	-989	989	866	1011,56	43,3	945,7	0,86	0,98	522,77
3	0	-798	798	855	1057,54	42,75	755,25	0,81	1,27	622,38
4	0	-788	788	842	1014,64	42,1	745,9	0,83	1,23	566,15
5	0	-2187	2187	1952	2115,08	97,6	2089,4	0,92	0,92	814,40
6	0	-2176	2176	1956	2069,1	97,8	2078,2	0,95	0,91	674,71
7	0	-2541	2541	1951	2069,1	97,55	2443,45	0,94	0,78	689,03
8	0	-633	633	538	690,9	26,9	606,1	0,78	1,05	433,47
9	0	-618	618	521	666,71	26,05	591,95	0,78	1,04	416,00
10	0	-613	613	519	667,87	25,95	587,05	0,78	1,05	420,34

Table 6. Exploitation of measures 09:43 to 09:49

N°	PV	BATTERY	DC BUS POWER	AC CHARGE POWER		Loss P_2	$P_{ccu}= P_{cc} - P_2$	PF	YIELD $S_c/(P_{ccu})$	Q_c (VAR)
	Prt (W)	Pb(W)	Pcc= Prt -Pb (W)	P_c (W)	S_c(VA)	Loss P_2 =0,05 *P_c	$P_{cc} - P_2$			
1	4180	3324,84	855,16	667	896,61	33,35	821,81	0,74	1,01	599,18
2	4201	3292,56	908,44	718	898,17	35,9	872,54	0,80	0,95	539,61
3	4205	3271,04	933,96	730	898,17	36,5	897,46	0,81	0,92	523,26
4	4205	3271,04	933,96	730	898,17	36,5	897,46	0,81	0,92	523,26
5	4233	2975,14	1257,86	1009	1287,44	50,45	1207,41	0,78	0,98	799,6
6	4216	3239,39	976,61	800	988,57	40	936,61	0,81	0,97	580,75
7	4260	3233,38	1026,62	820	1009,8	41	985,62	0,81	0,94	589,31
8	4282	3136,54	1145,46	824	1013,32	41,2	1104,26	0,81	0,85	589,78
9	4316	3281,8	1034,2	829	1013,32	41,45	992,75	0,82	0,94	582,73
10	4328	3308,7	1019,3	838	1011,56	41,9	977,4	0,83	0,95	566,57

From these tables, we have the following observations:

- The power Sc is substantially equal to Pccu and their ratio R≈1. The small difference is due to the other consumption of the other equipment connected to the bus and the measurement uncertainties. This confirms the law of conservation of energy.
- The active power consumed by the AC loads (Pc) is always lower than the direct current power (Pccu) supplied to the converter.

- For example, at the measurement sample 2 of table 7, the difference between the two powers is 258 “W”. This difference is explained by the fact that the power Pccu is divided into two active and reactive powers. In our measurement samples Qc reached a value of 1999, 204 VAR with a minimum power factor of 0.74.

Table 7. Exploitation of measurements 12:00 p.m. to 12:09 p.m

N°	PV	BATTERY	DC BUS POWER	AC CHARGE POWER		Loss P_2	$P_{ccu}= P_{cc} - P_2$	PF	YIELD $S_c/(P_{ccu})$	Q_c (VAR)
	Prt (W)	Pb(W)	Pcc= Prt -Pb (W)	P_c (W)	S_c(VA)	Loss P_2 =0,05 *P_c	$P_{cc} - P_2$			
1	3741	-202	3943	3405	3931,29	170,25	3772,75	0,866	0,95	1964,94
2	3800	-32	3832	3385	3931,29	169,25	3662,75	0,861	0,98	1999,20
3	3855	-114	3969	3387	3892,07	169,35	3799,65	0,87	0,94	1917,40
4	3932	-92	4024	3407	3938,13	170,35	3853,65	0,865	0,94	1975,15
5	2512	98	2414	1946	2395,12	97,3	2316,7	0,812	0,95	1396,31
6	2490	60	2430	1984	2441,18	99,2	2330,8	0,813	0,96	1422,35
7	2469	21	2448	1952	2390,96	97,6	2350,4	0,816	0,94	1380,71
8	2447	76	2371	1979	2505,91	98,95	2272,05	0,79	1,02	1537,25
9	2453	131	2322	1975	2459,93	98,75	2223,25	0,803	1,02	1466,50
10	2454	60	2394	1968	2441,18	98,4	2295,6	0,806	0,98	1444,41

Undersizingratio: U

If the only power taken into account is the active power, then there is an undersizing due to the fact that in operation the solar source (Panels and/or) battery will provide in addition to P, the reactive power Q therefore a total apparent power S which is greater than P.

So we then define the undersizing coefficient U:

$$U(\%) = \frac{S-P}{P} * 100 = \frac{1-\cos\varphi}{\cos\varphi} * 100 \qquad \text{(equation 22)}$$

If $\cos\varphi = 0,5$ then U =100%, i.e. a half undersized installation.

Measurement curves obtained: By synthesizing the data we obtain these tables which allow us to represent the characteristics of the installation. We also obtained the figures 11 , 12, 13, which represent the evolution of these synthesis parameters. From these summary tables of measurements, the maximum value of U is: 34.42% obtained at 9h:43mn:49s from table 9.

Table 8: Summary of measurements from 00:06 to 00:15

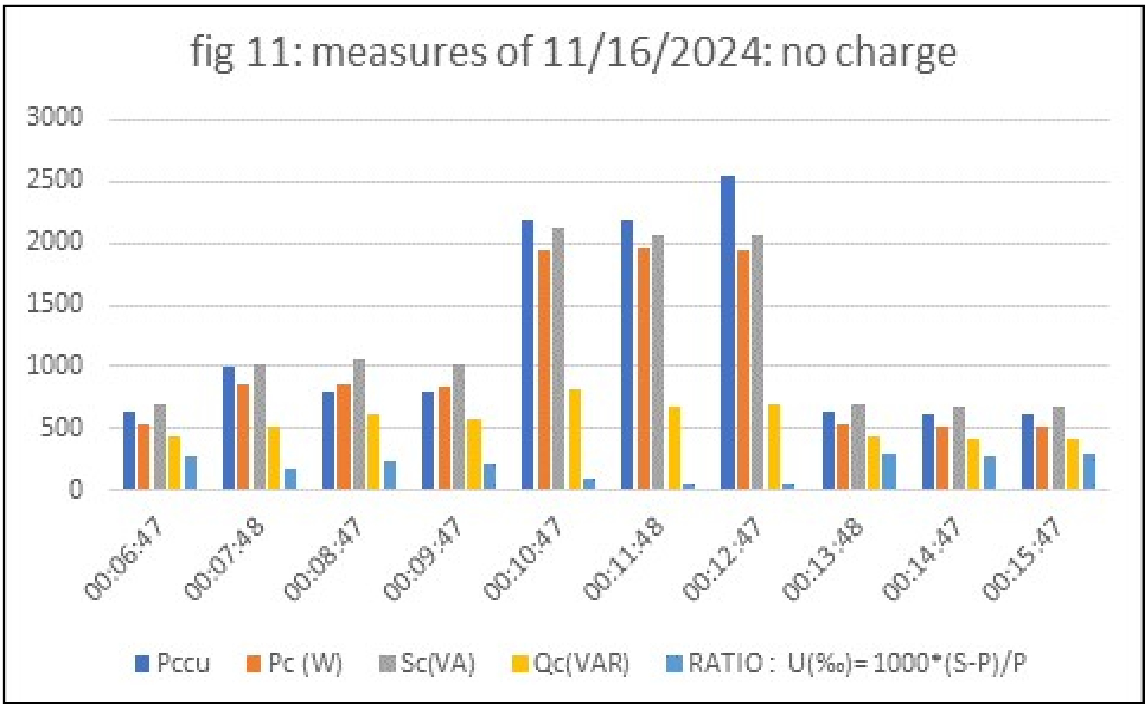
Time	Pccu	Pc (W)	Sc(VA)	Qc(VAR)	RATIO U(%)= 100*(S-P)/P	N°
00:06:47	636	544	690,9	425,92	27,00%	1
00:07:48	989	866	1011,56	522,78	16,81%	2
00:08:47	798	855	1057,54	622,39	23,69%	3
00:09:47	788	842	1014,64	566,15	20,50%	4
00:10:47	2187	1952	2115,08	814,41	8,35%	5
00:11:48	2176	1956	2069,1	674,71	5,78%	6
00:12:47	2541	1951	2069,1	689,04	6,05%	7
00:13:48	633	538	690,9	433,47	28,42%	8
00:14:47	618	521	666,71	416,01	27,97%	9
00:15:47	613	519	667,87	420,34	28,68%	10

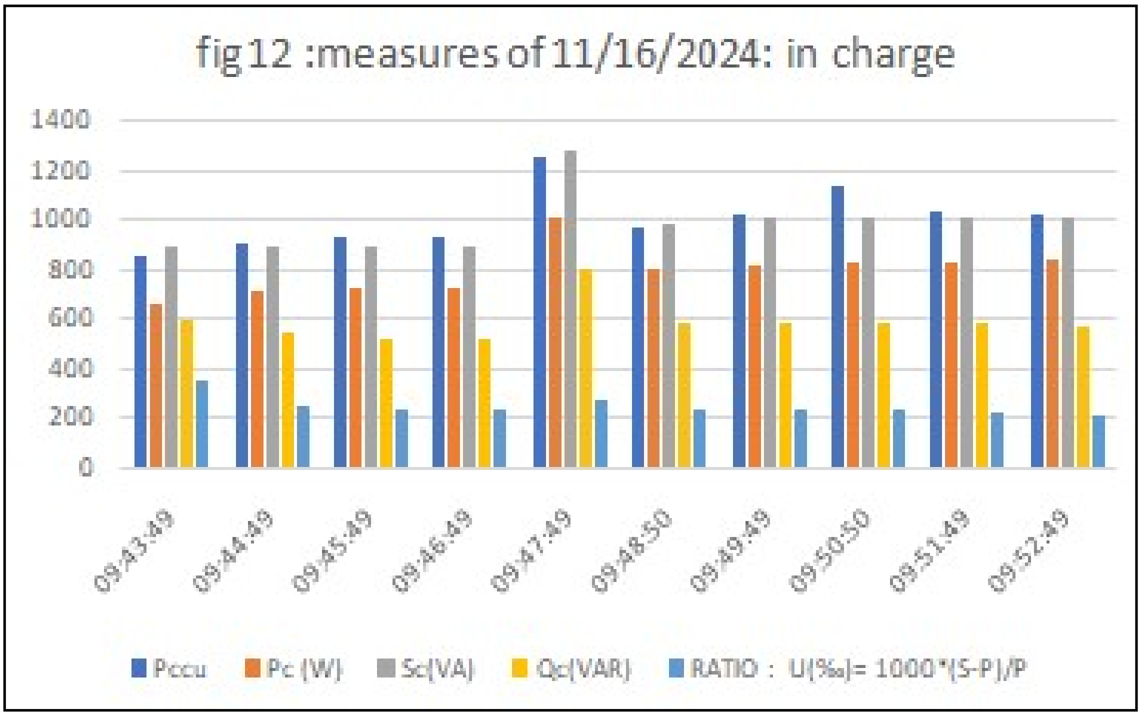
Table 9. Summary of measurements from 09:43 to 09:49

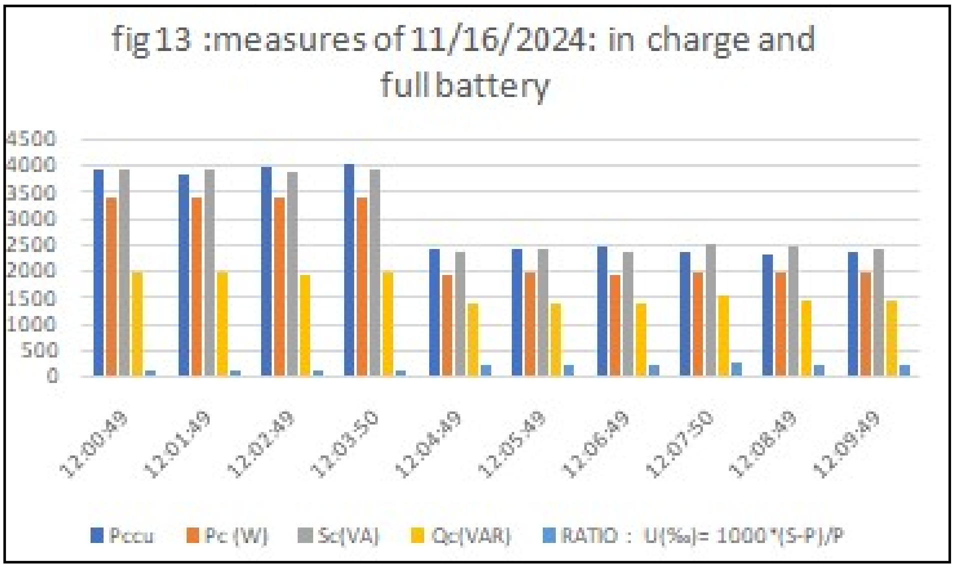
Time	Pccu	Pc (W)	Sc(VA)	Qc(VAR)	RATIO U(%)= 100*(S-P)/P	N°
09:43:49	855,16	667	896,61	599,18	34,42%	1
09:44:49	908,44	718	898,17	539,62	25,09%	2
09:45:49	933,96	730	898,17	523,27	23,04%	3
09:46:49	933,96	730	898,17	523,27	23,04%	4
09:47:49	1257,86	1009	1287,44	799,64	27,60%	5
09:48:50	976,61	800	988,57	580,75	23,57%	6
09:49:49	1026,62	820	1009,8	589,32	23,15%	7
09:50:50	1145,46	824	1013,32	589,78	22,98%	8
09:51:49	1034,2	829	1013,32	582,73	22,23%	9
09:52:49	1019,3	838	1011,56	566,58	20,71%	10

Table 10. Summary of measurements from 12:00 p.m. to 12:09 p.m

Time	Pccu	Pc (W)	Sc(VA)	Qc(VAR)	RATIO U(%)= 100*(S-P)/P	N°
12:00:49	3943	3405	3931,29	1964,947	15,46%	1
12:01:49	3832	3385	3931,29	1999,204	16,14%	2
12:02:49	3969	3387	3892,07	1917,404	14,91%	3
12:03:50	4024	3407	3938,13	1975,150	15,59%	4
12:04:49	2414	1946	2395,12	1396,311	23,08%	5
12:05:49	2430	1984	2441,18	1422,359	23,04%	6
12:06:49	2448	1952	2390,96	1380,719	22,49%	7
12:07:50	2371	1979	2505,91	1537,252	26,63%	8
12:08:49	2322	1975	2459,93	1466,503	24,55%	9
12:09:49	2394	1968	2441,18	1444,415	24,04%	10







CONCLUSION

Through this study, we have highlighted the influence of the power factor in the power provided by solar panels or batteries. We then propose two methods to take this into account:

Upstream by taking into account individual power factors

For N electrical equipment with active powers P_i and known power factors $\cos\varphi_i$ or known apparent powers S_i , the daily energy consumption of a piece of equipment is given by:

$$E_i = S_i * t_i = \frac{S_i}{\cos\varphi_i} * t_i \quad \text{(equation 23)}$$

The total energy is:

$$E_T = \sum_{i=1}^{N} E_i = \sum_{i=1}^{N} S_i * t_i = \sum_{i=1}^{N} \frac{P_i}{\cos\varphi_i} * t_i \quad \text{(equation 24)}$$

The estimation of peak power (equation 6) and battery capacity (equation 7) remains unchanged by replacing E_T with its new expression.

- Downstream, taking into account the average power factor of the installation:

For N electrical equipments with active powers Pi and average power factor $\cos\varphi$: The expression of the total energy E_T does not change according to the equation 5

The solar peak power is: $P_c = \frac{E_T}{h_i * k_1 * k_2 * \cos\varphi}$ (equation 25)

The battery capacity is: $\frac{E_T * AUT}{U * DOD * \gamma_b * \cos\varphi}$ (equation 26)

Failure to take this parameter into account when sizing solar installations results in an underestimation of solar power and battery storage capacity. Our study showed that reactive power not taken into account in solar installations can cause undersizing of 100% ($\cos\varphi = 0.5$), i.e. equality of active and reactive power.

This also means that the solar panels and storage batteries are underestimated by half. The direct consequence of this underestimation is the reduction by half of the autonomy and the life span of the batteries as well as cuts during calls for high power during periods of lack of sunshine. In conclusion, the untaken power factor is a factor affecting photovoltaic solar installations just like the temperature and the quality of the equipment. If it is not taken into account, reactive energy compensation is recommended.

REFERENCES

1. RAPPORT 2019 Chiffres clés sur l'énergie au Burkina Faso et dans l'espace UEMOA
2. Mémotech électrotechnique, René Bourgeois et Denis Cogniel, 1 janvier 1987, collection A. Capliez, page 131
3. https://www.civisol.fr/info/17-dimensionner-une-installation-photovoltaique-pour-site-isole?srsltid=AfmBOoryXdDao7tVQ50Oh-1F-Y5o4q5uS6mtJw_ZJu5GSmkZ-y3ChC8v , consulted on August 20, 2024
4. Thèse : Influence des modes d'alimentation et de gestion des réseaux d'éclairage sur la performance et la fiabilité des sources de lumière, DAVID BUSO, 16 décembre 2004, page 9
5. Commande d'une chaîne de pompage photovoltaïque au fil du soleil , A. Meflah , 29 septembre 2012
6. https://www.solar-electric.com/learning-center/the-benefits-of-victron-vrm/ , accessed September 1, 2024, on 10:25
7. Datasheet-SmartSolar-charge-controller-MPPT-250-70-up-to-250-100-VE.Can-FR
8. Datasheet-Inverter-1200VA-5000VA-FR
9. Thèse: Contribution à la conception par la simulation en électronique de puissance : application à l'onduleur basse tension, Cyril BUTTAY, novembre 2004, page 72
10. Mémotech électrotechnique, René Bourgeois et Denis Cogniel, 1 janvier 1987 , collection A. Capliez , page 157
11. https://culturesciences.chimie.ens.fr/thematiques/chimie-physique/electrochimie/evaluation-des-performances-des-batteries-li-ion accessed October 10, 2024 on 22:40