

Design of DC Wirings for Urban House in Indonesia Including Analysis on Appliances, Power Losses, and Costs: An alternative to Support Rooftop PV Uptake

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Abstract. Most of the application of solar PV in Indonesia uses inverter, which is a complex and expensive electronics system. Many of the PV plants are in fault condition due to the failure of the inverter. This paper proposed DC wirings powered by solar PV for houses in the urban area of Indonesia. First, the paper reviewed the availability of electrical appliances powered by DC voltage supply. Secondly, it presents AC and DC house wiring designs for a house with 1 300 VA electrical power limit. Losses of both wirings are analyzed and compared, including the cost of wirings materials. The survey showed appliances such as air conditioning, fridge-freezer, television, washing machine, and other appliances are now available in DC voltage supply. A 48 V DC bus is chosen to minimize losses. From a cost perspective, AC and DC wiring systems are comparable, but the DC house is slightly more expensive due to the cost of appliances. The cost of DC wirings is lower due to the lower cost of the DC-DC converters and uses fewer conductors. The results provide an alternative to using solar PV directly distributed as DC voltage for the houses in the urban area of the country.

Keywords: Cost of wirings, DC supply, DC appliances, renewable energy, wirings losses.

1 Introduction

The current contribution of renewable energy in the Indonesian energy mix is approximately 11.4 %, while the target for 2025 is 23 % and further increasing to 31 % by 2050 [1]. One of the potential renewable resources in the country is solar energy. The potential of solar photovoltaic is estimated at around 208 GW. The national plan is to achieve a solar PV capacity of 6.5 GW by 2025 [1]. However, the current total installed

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solar PV capacity is somewhat inconclusive but more likely around 100 MW. The current PV system deployment includes 1 MW to 5 MW large scale grid-connected PV, 10 kW to 100 kW both off-grid and grid-connected system, and low power solar home systems.

A solar PV system consists of solar PV modules, battery and charger controller, inverter, and electrical load. Naturally, the PV module generates DC voltage, and for low power applications, this output is directly connected to the load. However, for a larger load or connection to the grid, the DC output of the PV module has to be converted to an AC system using an inverter. The inverter is an electronics system which consists of dc-link bus, switching devices, switching controller, protection, data logging and monitoring, and communication module. With the advance of power electronics and its control, the inverter is a very efficient power conversion system. Today, the inverter is complex electronics and form a significant component of a PV system cost. Due to the complexity of the inverter make it one of the main factors that cause the failure of a solar PV system. The research reported in [2] showed that 43 % of solar PV failure is associated with the inverter. Observation of the 202 PV system in Taiwan found that 60 % of the failure is also associated with inverter [2, 3]. A similar situation is also observed in Indonesia. Although there has been no comprehensive research on the failure of solar PV, it has been reported many of the failures of solar PV is associated with the inverter. For example, it was reported that 18 out of 50 inverters of 1 MWp Karangasem grid-connected plant were in faults condition. A similar situation also occurred in 1 MWp Bangli grid-connected plant in which 30 out of 50 inverters were in a fault condition. The failure of the inverter may require replacement of the whole unit, and also, until it is getting fixed, it will cause a reduction of overall plant's output. Meanwhile, the government has planned to achieve 6 500 MW PV by 2025 means there would be a large number of inverters. If failure associated with the inverter continues, then it will become a problem in getting the PV plant to perform sustainably to meet the investment target, particularly the return of investment [2]. Therefore, solutions to overcome this challenge is desirable.

One alternative to overcome the problem associated with the inverter is to distribute the power in DC form hence eliminating the inverter from the system. This approach is known as DC house. In the last few years, the interest in using DC voltage system for home wirings increases. One of the backgrounds is today many domestic appliances are manufactured with DC voltage input. Also, the rapid development of solar PV, which naturally generates DC voltage output. Therefore, a DC voltage distribution system could be part of the solution. The advance of power electronics, particularly the DC-DC converter, has enabled a wide range of DC voltage regulation with high efficiency [4, 5]. One DC house project is developed by Cal Poly State University together with the Universitas Padjajaran and Technology Institute of the Philippine (TIP). DC house developed by Cal Poly uses 435 Wp solar PV [6] but research also to include wind turbine. DC house developed by Universitas Padjajaran is a brick house powered by 150 Wp solar modules and 300 W wind turbines [6]. DC house developed by TIP is a traditional bamboo house powered by a 500 Wp solar module [7]. The main motivation of this DC house project is to provide electricity for people who live in a remote area. Works on the use of low power DC voltage have been implemented successfully and also economical [8].

DC house projects as discussed above targeting houses in a remote area which typically have simple and low power demand. In terms of its potential to increase the capacity of PV, houses in the remote areas are relatively small compared to houses in urban areas. The urban population is large, and people in the city tend to have better social-economics characteristics in adopting solar PV for their homes. Also, there is a significant difference between households in remote and urban areas. Urban houses use a wide range of home appliances and consequently require a larger power supply and higher energy requirements. The energy-intensive usage of the urban society coupled with a better understanding of

energy-environmental issues makes this member of society become a highly potential user in supporting the acceleration of solar rooftop PV in the country [9]. Due to this background, this paper assesses how the urban society who has large power demand can benefit from the DC house approach as an alternative for solar PV application without using the inverter. There is little study regarding DC house for the urban area, but due to the proliferation of power electronics products, especially DC-DC converters, this application is explored in this paper.

The objective of this paper is to assess the technical feasibility of implementing a DC house for the population in the urban area of Indonesia. The study will review the availability of appliances commonly used in an urban house but powered with DC voltage. It will also review the customer of electricity in Bali and then nominate the largest number of the customer as an object for DC house wirings design. The review will then look at house-type commonly owned by people in an urban area. Wirings designs for both AC and DC installation for the nominated house-type will be presented, followed by an analysis of cost and power losses. The results of the study provide insight into the potential of DC house powered by solar PV as an alternative for future PV deployment in the urban area.

2 Material and methods

This paper presents the results of the study on the technical feasibility of implementing a DC house for the urban house as an alternative to the current solar PV deployment with the inverter. In the absence of inverter, PV system reliability potentially increases due to a fewer number of electronics circuitries, hence the economics of the project is likely more achievable, thus lead a sustainable solar PV deployment. The schematic of the research methodology is shown in Figure 1.

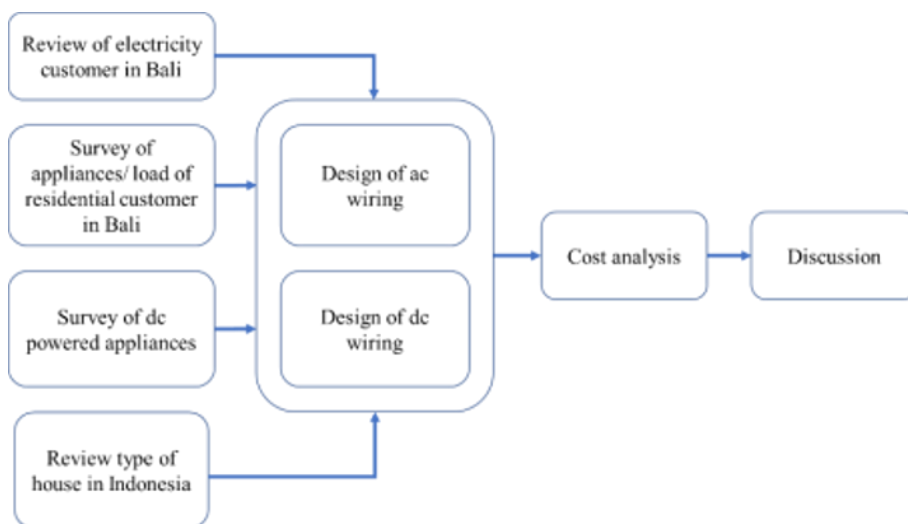


Fig. 1. Schematic of the research methodology.

A review of electricity customers in Bali is carried out to find out which type of customer is dominant. PLN Distribusi Bali is a utility company distributing electricity to the customer on the islands of Bali. The customer is grouped into different electricity tariffs. Currently, there are six-group of customers identified as residential, industry, business, government, social, and street lightings. Each group is further divided into subgroups based on the power limit set on the circuit breaker which connects premises with

the grid. The residential customer is divided into eight-groups. Once the type of residential customer is identified, then a survey is conducted to map the appliances or equipment used by the homeowner. The survey is carried in the Denpasar City area, which is the capital city of Bali and also the center of Bali's economy, which is a typical urban area of Indonesia.

Survey of DC powered appliances are conducted to find out if domestic appliances commonly used by the urban house is available in DC power supply. The availability of equipment is important when proposing this new area of application. For DC wirings, the availability of DC-DC converter is also important, and in fact, the idea of DC house is motivated due to the advent of power electronics, particularly DC-DC converter. The survey is an online survey looking at domestic e-commerce-based vendors and also international markets. To implement the design of the wirings, a house plan is needed to layout equipment/appliances based on the function of rooms or area of the house. For this purpose, a review of the housing type is carried out. Once the house type is nominated, the design of the wiring of the house can be done. Two wirings designs are proposed which uses standard AC wirings and DC wirings. The wirings will refer to Indonesian standards and regulation for wirings PUIL 2011 [10]. The schematic of the AC wirings is shown in Figure 2, and DC installation is shown in Figure 3.

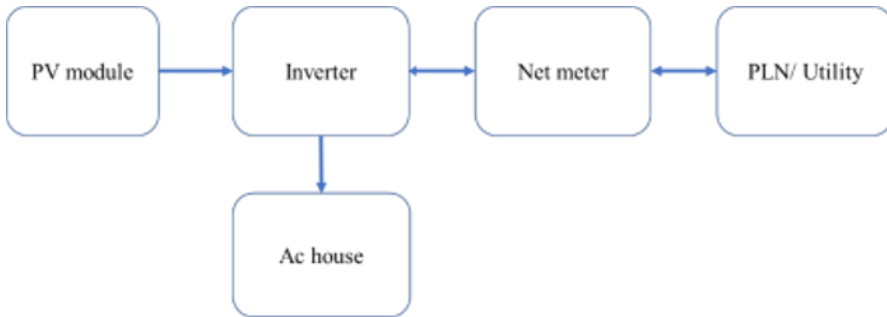


Fig. 2. Schematic AC house wirings.

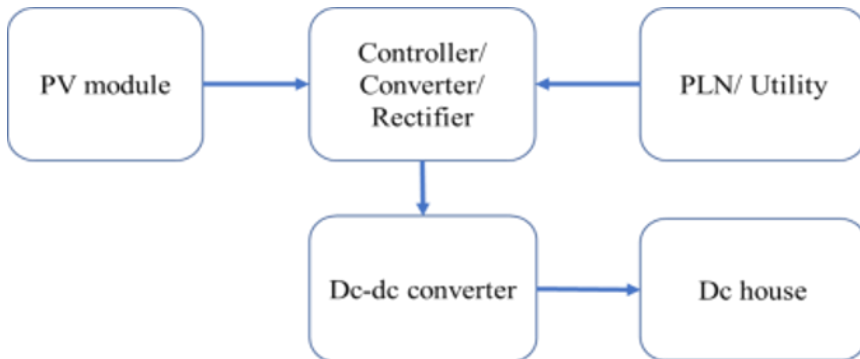


Fig. 3. Schematic DC house wirings.

Power losses considered in this paper are copper losses and power conversion losses. Copper losses are mainly losses on the conductor while power conversion losses are due to the conversion of electricity from AC to DC and when regulating DC voltage levels to suit the input required by the appliances. For AC circuitry, the losses are calculated using standard formulas based on effective values of the electrical parameters (Table 1).

Table 1. List of symbols.

GW	Gigawatt	AC	Alternating Current
MW	Megawatt	R1	Residential customer type 1 with kWh meter
MWp	Megawatt peak	R2	Residential customer type 2 with kWh meter
kW	Kilowatt	R3	Residential customer type 3 with kWh meter
Wp	Watt peak	R1T	Residential customer type 1 with pre-paid/token
W	Watt	R2T	Residential customer type 2 with pre-paid/token
VA	Volt Ampere	R3T	Residential customer type 3 with pre-paid/token
PV	Photovoltaic	R1M	Residential customer type 1 subsidy
DC	Direct Current	R1MT	Residential customer type 1 subsidy token

3 Results and discussion

Nationally, the number of electricity customers is dominated by residential, and this is also encountered in Bali. In 2017, the number of residential customers in Bali was 1 081 694, or 82 % of the total customers [11] The composition of electricity customers in Bali in 2017 is shown in Figure 4. Residential customers are further grouped into several subgroups; R1, R2, R3, R1T, R2T, R3T, R1M, and R1MT. In 2017, the total number of R1 and R1T customers combined was 699 697, or 66 % of the total residential customers in Bali. The subgroups of residential customers are shown in Figure 5. The R1 and R1T customers have 1 300 VA circuit breaker at the incoming point of PLN’s grid. These two customers type are essentially similar but differ only in the payment method. An R1 customer is billed based on energy meter reading installed at the premises, but for the recently connected R1T customer, the connection uses the pre-paid meter. The R1T customer is an R1, but with “token” payment hence the letter T. Geographically, the R1 customers are located in the southern part of Bali near Denpasar city.

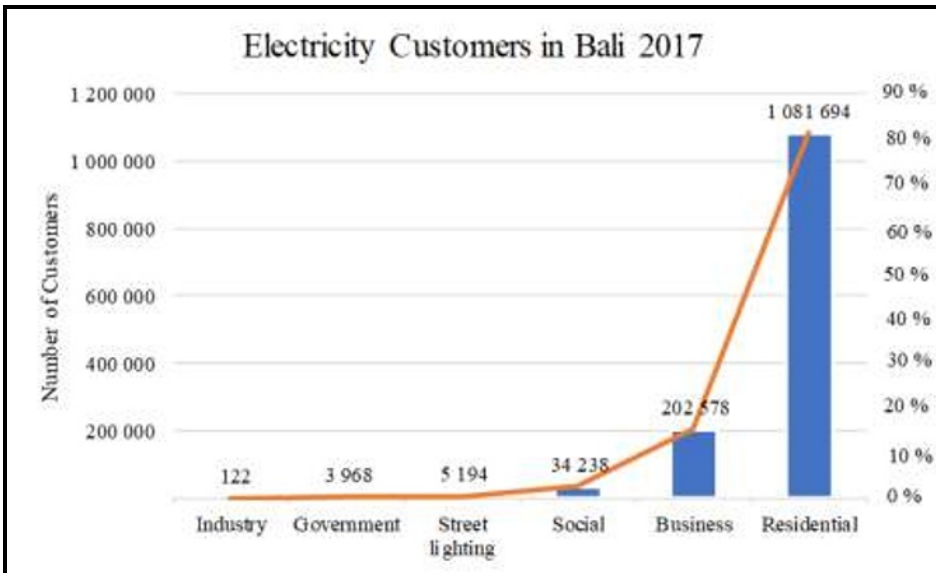


Fig. 4. Customer type.

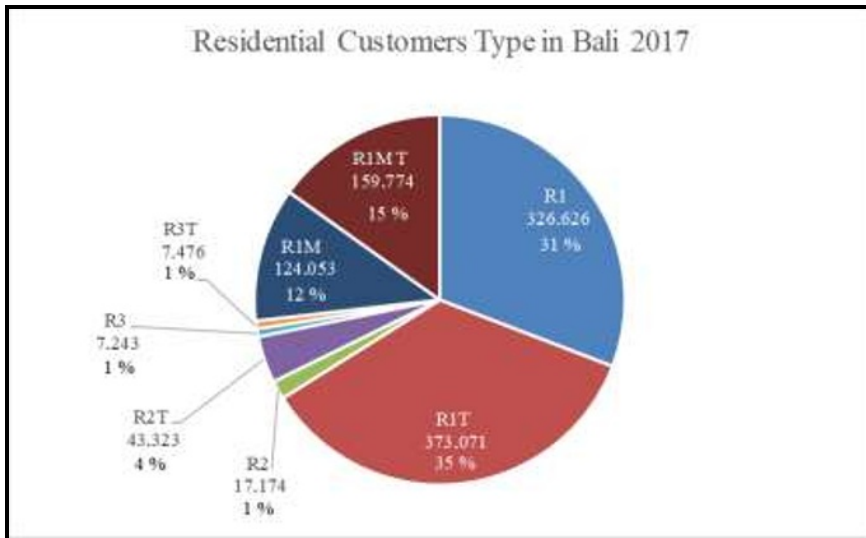


Fig. 5. Subgroups of residential-type customer.

The survey on appliances used by the 1 300 VA residential-type in Bali showed the following appliances: fridge and freezer, television, lights/lamps, rice cooker, iron, washing machine, water pump, air conditioning, and fan. Based on this result, a further survey is conducted to find out if these appliances are available in DC power supply. Through an online survey on a national and international e-commerce website, it was found that all of the appliances are available in DC-power supply mode.

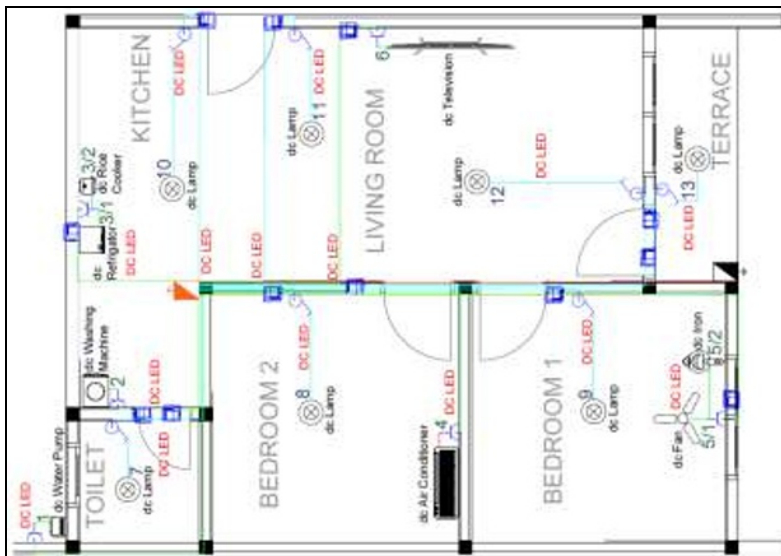


Fig. 6. Lay-out of type 45 house with 1 300 VA power connection.

Before designing the house wirings, which mainly involves installing termination points for appliances at a specific location, then the house and its room layout are necessary. A particular home is selected by reviewing house-type commonly built in Indonesia. The current regulation identifies the house based on the total area of the floor. According to the regulation, the house is divided into several types, such as 21, 36, 45, 54, 60, 70, and 120 [12]. For example, house-type 45 means the house has a total floor area of 45 m². The

review showed that the most popular small family house in Bali is type 45. This house is usually built as a one-floor building on a-100 m² land. This house is popular because its total area is sufficient for a small family, and its price is affordable. The house typically consists of two bedrooms, a kitchen, a dining room, a living room, and a bathroom with a toilet. The layout of the house is shown in Figure 6.

Figure 6 also shows wirings design both for AC and DC supply. The two models use a similar layout, and also similar appliances except the power supply are different; one uses standard AC power from the utility, and the other uses solar PV and distributed throughout the house using DC voltage. The occupant of the house is expected to get the same level of comfort when the house operates under the DC wirings. Table 1 shows the components of the AC wirings cost, which consists of the cost of appliances, inverter, and wires. The appliances are 46.5 % of the overall cost, inverter at 25.49 %, and wires are 28.01 %. Table 2 shows that power losses on the AC wirings circuits are very small. The low losses are clearly due to the use of high voltage. The power losses are 0.1 % for all loads.

Table 1. Cost components of AC wirings.

Components	Cost (IDR)	Percentage (%)
AC Appliances	12 338 634	46.50 %
Inverter	6 764 290	25.49 %
AC Wirings	7 432 500	28.01 %
Total	26 535 424	

Table 2. Specification of appliances and its AC wirings.

AC Appliances	Power (W)	Volatage (V)	I (A)	Length of cable (m)	Resistance of cable (Ω)	Copper losses (W)
Water pump	350	220	1.872	12.550	0.144	0.504 1
Washing machine	250	220	1.337	11.375	0.130	0.233 1
Refrigerator	100	220	0.535	9.000	0.103	0.029 5
Rice Cooker	395	220	2.112	9.000	0.103	0.460 5
Air conditioning	390	220	2.086	6.250	0.072	0.311 7
Fan	220	220	1.176	3.250	0.037	0.051 6
Iron	350	220	1.872	3.250	0.037	0.130 5
Television	100	220	0.535	8.175	0.094	0.026 8
LED lamps	18	220	0.096	10.450	0.120	0.001 1
	18	220	0.096	6.250	0.072	0.000 7
	18	220	0.096	3.250	0.037	0.000 3

Table 2. continue to the next page.

Table 2. (continued).

AC Appliances	Power (W)	Volatage (V)	I (A)	Length of cable (m)	Resistance of cable (Ω)	Copper losses (W)
	18	220	0.096	10.975	0.126	0.001 2
	18	220	0.096	8.475	0.097	0.000 9
	18	220	0.096	3.675	0.042	0.000 4
	18	220	0.096	3.675	0.042	0.000 4

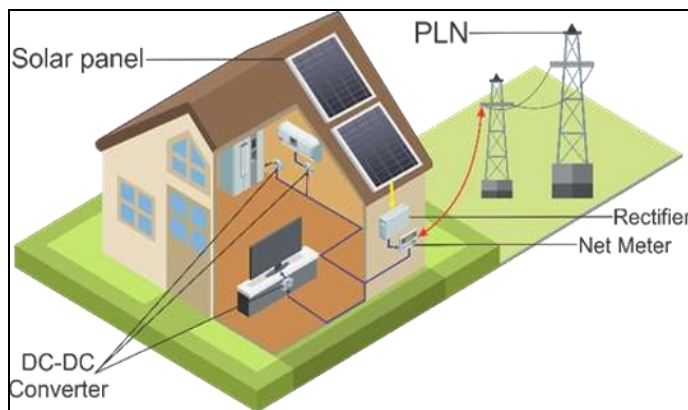


Fig. 7. Schematic of DC wirings.

The schematic of the residential house supplied with solar PV and also connected to the grid is shown in Figure 7. The wirings block diagram of DC voltage distribution using a 48 V bus system is shown in Figure 8. A list of DC powered equipment for the DC house is shown in Table 3. The technical specification of the DC-DC converter used for the level-shifting of the voltage is shown in Table 4. Solar PV will supply power to the house during day time whenever the sun is available, and at other times PLN will take over. To increase the penetration of solar PV, energy storage can be implemented but will increase the overall cost.

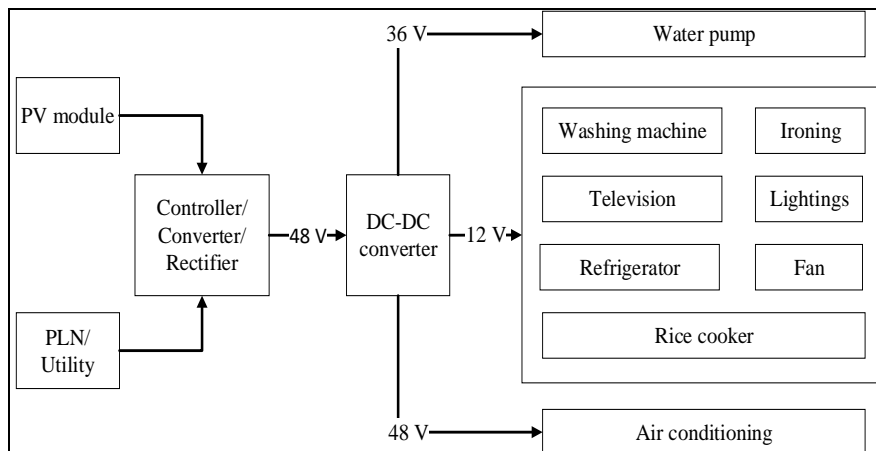


Fig. 8. Schematic of 48 V DC house

Table 3. Components of DC wirings

AC Appliances	Power (W)	Volatage (V)	I (A)	Length of cable (m)	Resistance of cable (Ω)	Copper losses (W)
Water pump	210	48	4.375	6.250	0.072	1.372
Washing machine	150	48	3.125	4.450	0.051	0.498
Refrigerator	60	48	1.250	3.350	0.038	0.060
Rice Cooker	380	48	7.917	3.350	0.038	2.408
Air conditioning	500	48	10.417	6.250	0.072	7.776
Fan	10	48	0.208	9.250	0.106	0.005
Iron	150	48	3.125	9.250	0.106	1.036
Television	65	48	1.354	3.350	0.038	0.070
LED lamps	20	48	0.417	4.450	0.051	0.009
	20	48	0.417	2.950	0.034	0.006
	20	48	0.417	6.250	0.072	0.012
	20	48	0.833	4.750	0.054	0.038
	20	48	0.417	5.750	0.066	0.011
	20	48	0.833	7.750	0.089	0.062
	20	48	0.417	7.750	0.089	0.015

Table 4. Technical specification of DC-DC converter

Parameter	Value
Manufacturer	RCNUN
Model number	RC481215
Input voltage rating	10 V to 60 V DC
Output voltage rating	12 V to 48 V DC
Rate current	10 A to 20 A
Rate power	120 W to 360 W
Conversion efficiency	± 94 %
Voltage regulation	± 1 %
Load regulation	± 2 %
Ripple (Full load test)	< 160 mV
No-load current	< 60 mA
Working temperature	-55 °C ~ +125 °C
Waterproof rating	IP67
Protection	Over-current short circuit protection
Dimension	74 mm \times 74 mm \times 32 mm
Warranty	10 yr

Table 5. Cost components of DC wirings.

Components	Cost (IDR)	Percentage (%)
DC Appliances	20 163 000	73.77 %
DC-DC Converter	2 213 250	8.10 %
DC Wirings	4 955 000	18.13 %
Total	27 331 250	

As shown in Table 5, the cost of implementing DC wirings is dominated by the cost of appliances, as also the case in traditional AC wirings. The total cost of appliances is 73.77 %, the DC-DC converters are 8.10 %, and wires are 18.13 %. DC appliances cost more expensive than the AC version, which likely associated with the mass-production of the equipment. The composition of appliances on the DC wirings is shown in Figure 9. The cost of appliances is dominated by high-power devices such as air conditioning, fridge-freezer, television, and water pump. AC powered machines have been around for such a long time hence the cost of manufacturing, and retail price become low compared to DC powered appliances, which are still limited, therefore cost more expensive. Another finding is the cost of power conversions on the two wirings are significantly different. AC wirings use the inverter, which costs more expensive even with DC-DC converters all combined. All the DC-DC converters only cost 8.10 % from the cost of the overall wirings or around a third of the inverter’s cost. The cost of conductors for DC wirings is also lower due to the use of a fewer number of conductors. AC wirings require three conductors while DC wirings only two conductors. In terms of power losses, DC wirings using 48 V bus voltage generate losses of 0.8 % for all loads. Lower DC voltage level generates higher losses, as shown in Figure 10.

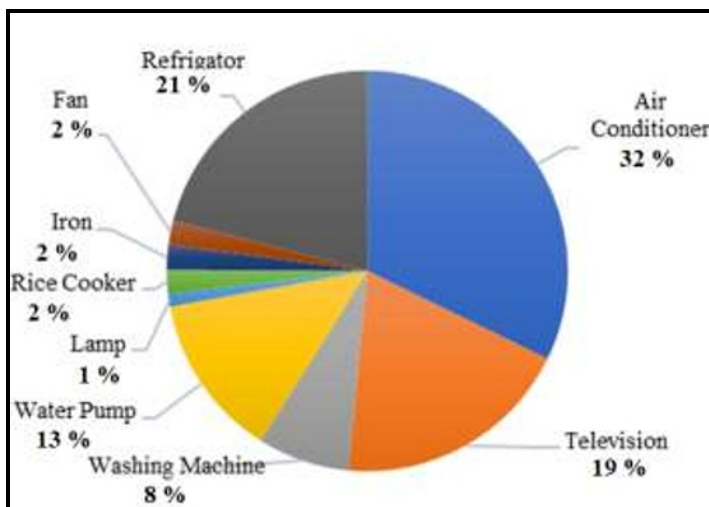


Fig. 9. Composition of DC appliances.

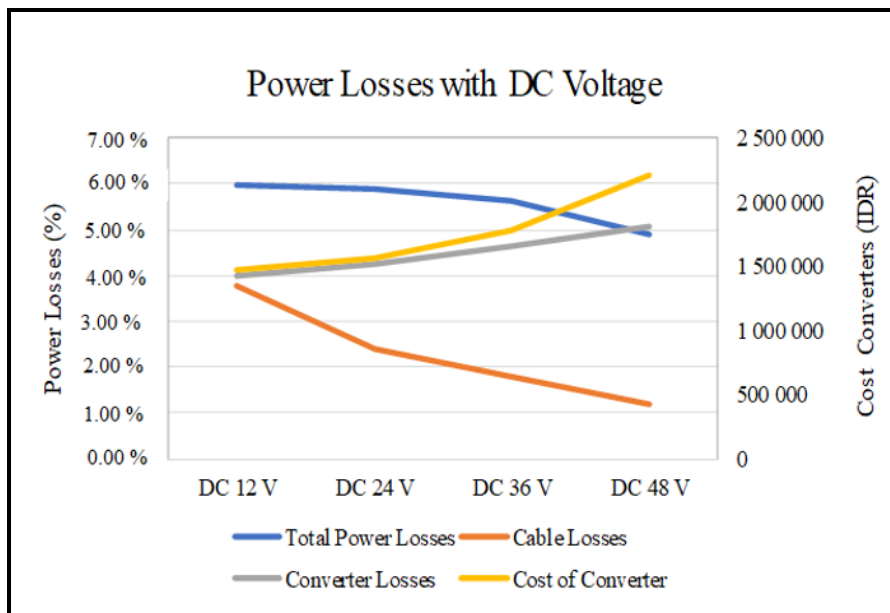


Fig. 10. Power losses.

4 Conclusions

This paper has presented the design of DC wirings for the small urban house in Indonesia, commonly referred to as house-type 45 and supplied with solar PV without an inverter. The house has a 1 300 VA power ceiling. The wirings consist of DC appliances such as washing machines, air conditioning, water pumps, and including lightings typical for an urban house. Voltage level conversion is done using RC481215 DC-DC converter with high efficiency and a small footprint to regulate the voltage to suit voltage input of the loads. The comparison shows that AC and DC wiring costs are comparable with DC wirings slightly higher due to the cost of appliances. The cost of power conversion devices in DC wirings is much lower than in AC wirings. Although in DC wirings, it uses many DC-DC converters, its total cost is only 30 % of the cost of the inverter. Also, the cost of conductors in DC wirings is lower than that of AC because it uses fewer conductors. A 48 voltage system is proposed to minimize the losses. DC wirings have greater wirings losses than the AC wirings since distributing electric power with lower voltage will impose higher power losses. The results presented here provide insight into the possibility of using DC wirings in the urban house. It has been shown that DC wirings have potentially higher reliability due to the absence of inverter and sustainable due to lower cost of DC-DC converters should it requires replacements.

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