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DC microgrid in residential buildings

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DC Microgrid in Residential Buildings

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15.1 Introduction

A microgrid is an innovative control and management architecture at the distribution level, which makes it easy to implement smart grid techniques at power distribution level [1]. Depleting of fossil fuels, reducing the emission of greenhouse gases, and increasing energy demand are main factors responsible for the growing penetration of photovoltaic (PV) generators to power distribution grids [2]. The distributed generators (DGs) have the potential to provide ancillary services under these circumstances. For example, they may have many functions such as instantaneous power reserve, emergency supply, and peak power saving. The PV system with distributed generation is a good solution for electrification to poorly grid connected or isolated area. This concept easily works in both the AC and DC microgrid system [3]. However, the implementation of the DC microgrid

simplifies and provides the opportunity to integrate the renewable energy resource (RES) such as PV system, and fuel cells without converting into AC [4]. These are intrinsically DC power source at higher efficiency. Additionally, the loads used in buildings may be DC load or AC load which can be converted into DC. The rapid developments in the DC technologies, the DC loads, are more energy efficient than the AC loads [5]. The DC output power of PV systems can be used directly without conversion into the low voltage direct current (LVDC) distribution system [6].

There are no inductive, capacitive, and skin effects in the DC system. The DC system has a better voltage regulation than the AC system because there is no inductive effect on steady state[3]. Additionally, the power loss due to charging and discharging of the capacitor is eliminated in the DC system. So overall there is less power loss in the DC system [7]. Due to the absence of the skin effect, the entire cross-section area of the line conductor is used in the DC system. It means a thinner conductor could be used for DC systems and it reduces the line conductor weight. Additionally, as the cross-sectional area is inversely proportional to the conductor resistance, the DC system has less line resistance than the AC system [7]. In this way, the direct current distribution system improves the system efficiency. Additionally, the local utilisation of the energy reduces the transmission and distribution losses and may reduce the shortage of electricity. In this chapter, analysis and comparison between AC and DC microgrid in residential buildings have been done based on appliances, converters and their power losses in both systems. The layouts for LVDC distribution network have been discussed. Both unipolar and bipolar layouts of LVDC system have been discussed. Two microgrid system configurations have been discussed: AC residential building (i.e. AC distribution system with DC appliances) and DC residential building (i.e. distribution network with DC appliances).

15.2 Conceptualization: DC Microgrids in Buildings

A microgrid refers to a power distribution system integrated with distributed energy resources (DERs) and controllable loads, which can either operate with the main grid (i.e., grid-connected mode) or use the DERs to supply the loads without the main grid (i.e., islanded mode) [6]. It can be viewed as a small-scale grid, and it is widely considered as one of the key components to integrate renewable DERs and save transmission losses for efficiency.

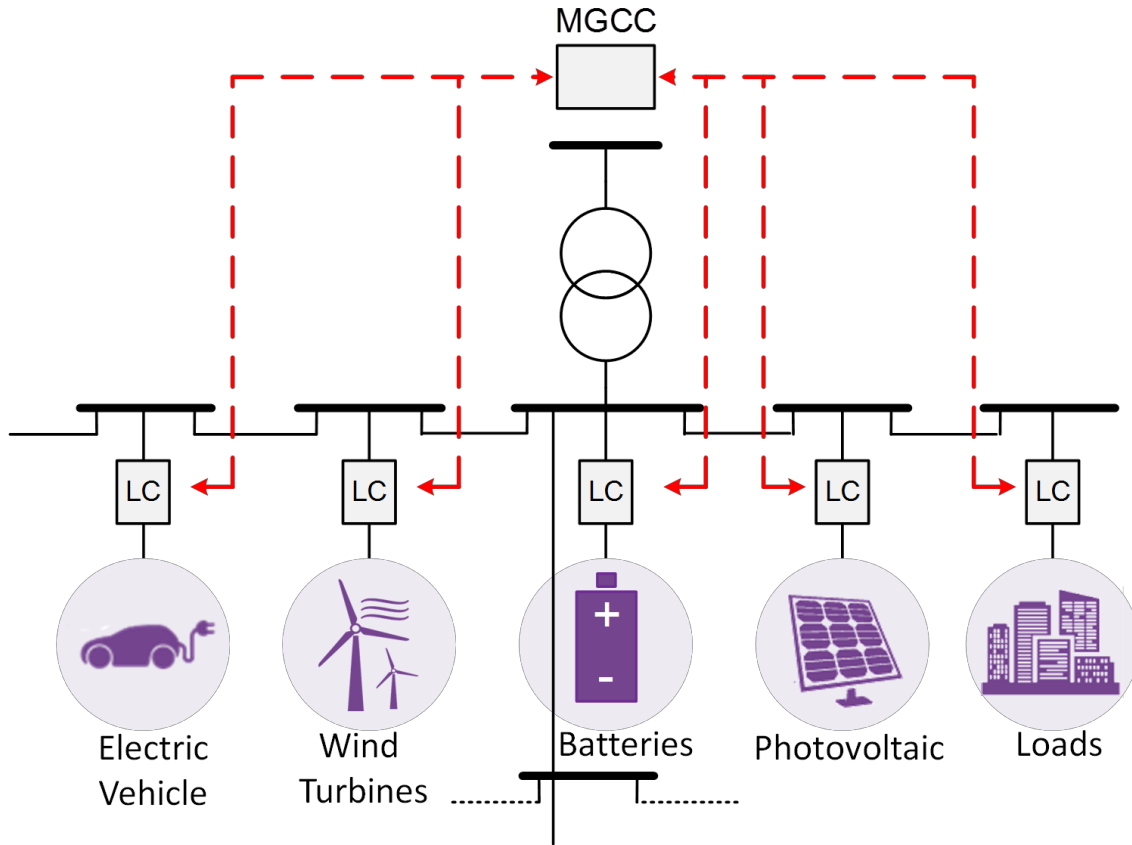


Figure 15.1. Conceptual layout of a microgrid including microgrid central controller (MGCC) and local controllers (LCs).

In a conventional power system, the power flow is a single directional from bulk generation, e.g., a power plant, to load via a transmission and distribution network. As more DERs (such as roof-top PV system, small wind turbines -WTs), battery system, etc.) are becoming available on the distribution side, the bi-directional power flow is now possible, and it makes the conventional power distribution system into a microgrid which can use only the DERs as the power supply without the main grid (i.e., islanded mode) or even sell back its surplus power to the main grid. The size of a microgrid may vary depending on the application. For example, the concept of microgrid can be implemented as smart home, smart building, even a smart campus. Figure 15.1 shows a microgrid example consisting of photovoltaic (PVs), wind turbines (WTs), electrical vehicle, batteries, and loads. Two-way communications are available between the local controllers (LCs) and the microgrid central controller (MGCC).

15.3. Classification of Microgrids

The microgrids can be classified into three categories based on the type of supply system used by the distribution grid.

15.3.1 AC Microgrid System

A typical structure of an AC microgrid system interconnected with medium voltage (MW) system at the point of common coupling (PCC) is shown in Figure 15.2. The main system might be an AC or DC bulk system. The distributed generation (DG) units and energy storage system (ESS) are connected at some points within the distribution networks. Part of the network consisting of the DG units and load circuits can form a small isolated AC electric power system, i.e. an ‘AC microgrid’. During normal operating conditions, the two networks are interconnected at the PCC while the loads are supplied from the local sources (e.g. the RES based DG units) and if necessary from the utility. If the load demand power is less than the power produced by DG units, excess power can be exported to the public utility.

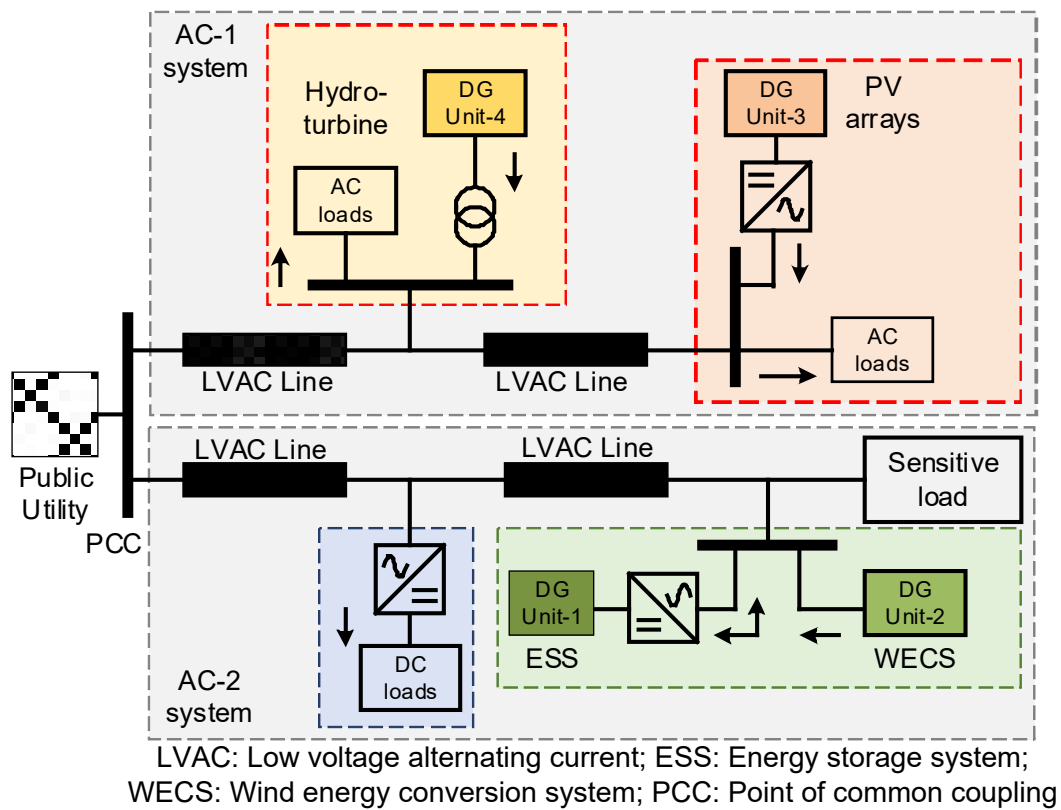


Figure 15.2. The general structure of AC microgrid with DG units and mixed types of loads.

15.3.2 Hybrid AC-DC Microgrid System

The general structure of a hybrid AC-DC microgrid is depicted in Figure 15.3. After staying on AC technology in the area of electric power supply, the DC power systems join it due to technological advancement in DC technology for power conversion, generation, transmission, and consumption. However, there are many challenges in DC technologies. Therefore, DC technologies should be integrated into the power system by

applying the algorithms at some places [8]. The scope to explore the DC technologies with its specific advantages is the microgrid. The hybrid AC-DC microgrids facilitate benefits of both the technologies and these are having the integration of AC technology with the DC technology. In a leading hybrid AC-DC microgrid system the AC and DC buses are connected through interlinking, bi-directional converters. However, this interlinking creates a stability issue and requires control algorithms to maintain the power quality. Microgrids, which are having different types of sources, and loads are the type of AC-DC systems [9].

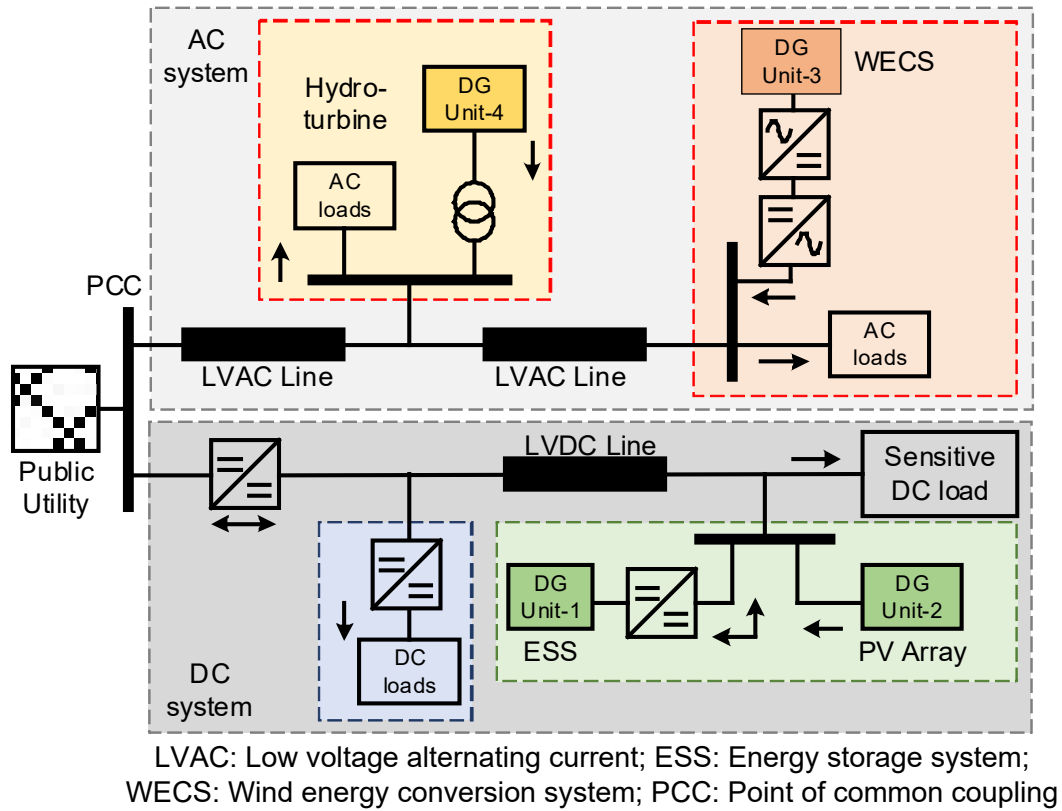


Figure 15.3. The general structure of Hybrid AC-DC microgrid with DG units and mixed types of loads and generators.

15.3.3 DC Microgrid System

The traditional electric power system was designed to move the central station AC power, via high-voltage AC (HVAC) transmission lines and lower-voltage distribution lines to households and businesses that use the power in incandescent lights, AC motors and other AC equipment for heating and cooling. Meanwhile, the DC power system has been used in industrial power distribution systems, telecommunication infrastructures and point-to-point transmissions over long distances or via sea cables and for interconnecting AC grids with different frequencies. Power electronics devices dominate today's

consumer equipment and tomorrow's DG units [10]. These devices (such as computers, fluorescent lights, variable speed drives, households, businesses, industrial appliances and equipment) need DC power for their operation. However, all these DC devices require conversion of the available AC power into DC for use, and the majority of these conversion stages typically use inefficient rectifiers. Moreover, the power from DC-based DG units must be converted into AC to tie with the existing AC electric network, only later to be converted to DC for many end users. These DC-AC-DC power conversion stages result in substantial energy losses. Using the positive experiences in the HVDC operation and the advance in power electronics technology, interests to use effective solutions have increased. Figure 15.4 shows typical DC microgrid system interconnected with the main systems at PCC which can be a medium voltage AC (MVAC) network from the conventional power plants or an HVDC transmission line connecting an offshore wind farm.

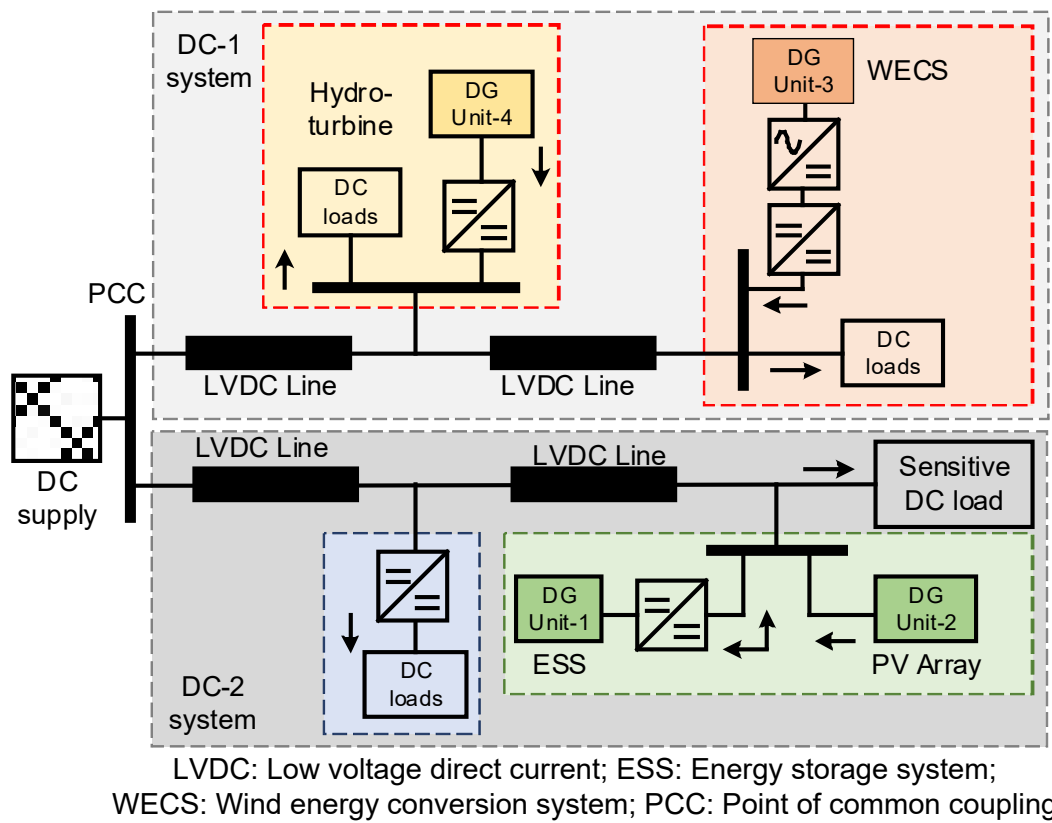


Figure 15.4. General structure of DC microgrid with DG units and mixed load and Generator types.

15.4 Topologies for DC Microgrid for Residential Applications

There are several topologies used by the DC micro-grid. However, the unipolar or bipolar type structure is typically used to configure the DC microgrid.

15.4.1 Unipolar LVDC System

The unipolar system consists of a two-winding transformer and a line converter, connected as shown in Figure 15.5. In a unipolar DC system, the line and loads are connected via two conductors, a neutral and other a positive polarity DC voltage. The unipolar system has a one voltage level for energy transmitted. All the customers are connected to this one voltage level [10]. The unipolar system has the small power transfer capacity compared to bipolar type system with the same voltage level (i.e. 12 and ± 12 V) and does not have a broad range of choices of DC voltage level.

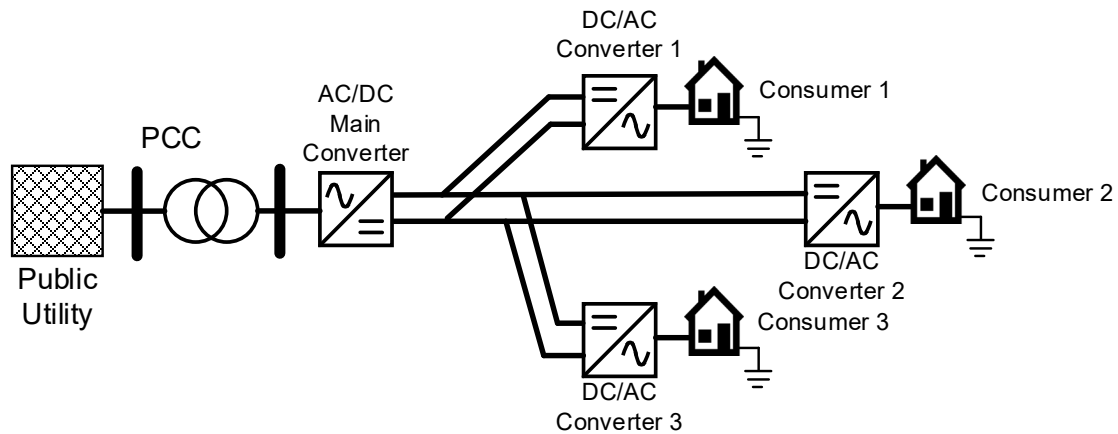


Figure 15.5. Unipolar LVDC distribution system used in a cluster of residential buildings.

15.4.2 Bipolar LVDC System

The bipolar system is a combination of a three-winding transformer, and two line converters, connected as shown in Figure 15.6, i.e. the bipolar system is a combination of two unipolar systems connected in series. The connection alternatives may be between a positive pole and neutral, between a negative pole and neutral, between positive and negative poles. The bipolar system provides a broad range of DC voltage levels compared to the unipolar system [11]. In the bipolar type, the system requires more components and the system may result in an unbalanced situation when the loads are not identically connected.

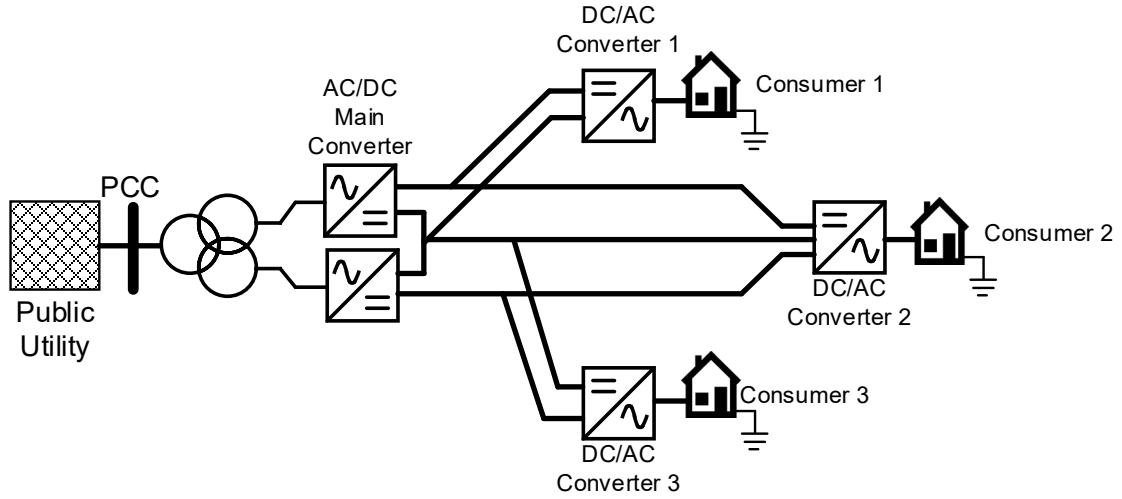


Figure 15.6. Bipolar LVDC distribution system used in a cluster of residential buildings.

15.5 Mathematical Analysis of AC vs DC Microgrid System

In this section, mathematical descriptions have been derived to calculate voltage, current and power losses during an AC as well as DC distribution system supply.

15.5.1 Total Daily Load

The total daily load (TDL) has been calculated with respect to the different DC voltage level supply as well as the different AC voltage levels and inverter efficiencies. When the DC load is connected to the system, then the DC load (γ) in amperes is given as:

$$\gamma = \frac{k}{V_{dc}} \quad (15.1)$$

where, k is the load rating in kilowatt; V_{dc} is the DC system voltage; and total daily load (TDL), L_{dc} , can be obtained by multiplication of the DC load with the number of operating hours (χ) of the load per day in ampere hours and it can be expressed as:

$$L_{dc} = \gamma \times \chi \quad (15.2)$$

If there is a variable DC load connected to the system, the calculation of total daily load is as follows:

$$L_{DC} = \sum_{j=1}^{\Omega} \gamma_j \chi_j \quad (15.3)$$

where, $\gamma_1, \gamma_2, \dots, \gamma_{\Omega}$ and $\chi_1, \chi_2, \dots, \chi_{\Omega}$ are variable DC loads in amperes and different time instants at which DC loads are switched ‘ON’ in a day.

If the AC load is connected to the system, then the AC voltage must be converted to DC voltage and the inverter efficiency is also considered. The DC load of the AC system can be expressed as:

$$\gamma = \frac{k}{V_{dc} \eta_{inv}} \quad (15.4)$$

Table 15.1 shows the characteristic values of a DC system based on the type of load (AC or DC load). If the DC load 2.4 kW is supplied at 24 Volts and 48 Volts, the total daily load (TDL) is 2,400 Ah, 1,200 Ah respectively. In the case of 2.4 kW AC load at 120 Volts and 220 Volts supplied by the same efficiency inverter (92 percent), then TDL is 2,609 Ah remains the same but higher than the TDL as obtained in the case of 2.4 kW DC load at 24 Volts. If a 2.4 kW AC load supplied at 220 Volts by the 95 percent efficiency inverter the obtained is TDL 2,526 Ah. The above calculation shows that TDL depends upon the DC system voltage and inverter efficiency. If the inverter efficiency is high, the losses in DC to AC conversion are less, and the system TDL will be reduced. As the system voltage is high, the system TDL will also decrease, i.e. system losses may decrease. On the other hand, if there is a lower inverter efficiency or DC supply voltage, the TDL will be higher. It means the battery bank will discharge at the fastest rate, which may decrease the battery lifetime and efficiency.

Table 15.1. Illustrative values of Total Daily Load on DC and AC Systems.

System Voltage	Power Rating (kW)	Inverter Efficiency (%)	Total Daily Load (Ah)
24V DC	2.4	-	2,400.0
48V DC	2.4	-	1,200.0
120 V AC	2.4	92%	2,608.7
220 V AC	2.4	92%	2,608.7
220 V AC	2.4	95%	2526.3

15.5.2 Voltage, Current and Power Losses in DC Supply

In India, the AC distribution system for residential buildings is single phase 230 Volt (RMS). The equivalent DC voltage (325 volts) applied to the same load can reduce the current ratings. For example, 230 Volts and 110 Volt AC supply the current rating can be reduced to 30 percent and 70 percent respectively [6-7]. The DC system voltage stress equivalent to the single-phase AC system can be calculated as:

$$V_{DC} = \sqrt{2} V_{AC} \quad (15.5)$$

The DC system has less potential stress compared to the AC system for the same voltage. For example, if a system is designed for 230 V AC, it can bear 325 V DC without any rapture in insulation. The voltage level helps to reduce the gap between two conductors of the distribution line. The less potential stress and weight of conductor reduce the size of the tower and insulator. This decreases the cost of the system and makes the system more economical. The power transfer in a DC system can be expressed as:

$$P = V \times I \quad (15.6)$$

The current in a DC system can be expressed as:

$$I = \frac{P}{V} \quad (15.7)$$

where P is the transferred power, V and I are the system voltage and current respectively. As shown in equation (15.7), if DC voltage is applied instead of AC voltage then the insulation can bear higher voltage stress, which allows applying higher DC voltage for the same system. The current is inversely proportional to the voltage. It means as the system voltage increase, their current will decrease. Therefore, the system copper losses (p) will also decrease.

$$p = I^2 R \quad (15.8)$$

where p represents power losses in the system and R is the resistance of the feeder cable.

The AC and DC system comparison in terms of current and power losses can be found in Table 15.2. The current and power losses in the 325 Volt DC system (equivalent to 230 Volt AC system) are approximately one third and a half respectively as compared to the 230 Volt AC system (single-phase AC voltage level in India). Additionally, it has around 2/3 times and 7/8 times less current flow and power losses respectively as compared to the 110-volt AC system (single-phase AC voltage level in the US).

Table 15.2. Comparative analysis of AC and DC system based on current rating and power losses.

DC Voltage	AC Voltage	Reduction in Current Rating	Reduction Power losses
------------	------------	-----------------------------	------------------------

325	230	29.2%	50.1%
325	110	66.2%	88.5%

Table 15.3 shows the energy savings, which can be obtained by switching from AC technologies to the most energy efficient DC-internal technologies. It is seen from the Table 15.3, that the total energy saving using DC technology in the residential loads is varying between 30 percent to 71 percent. Some rectifier losses have already existed in a few cases like a refrigerator, cloth washer and fans, in AC system.

Table 15.3. Possible Energy Saving using most Efficient DC Internal Technology based Appliances.

Appliances	Efficient DC Compatible Replacement Technology	Total Energy Savings
Fan	Run by brushless DC motor in place of single-phase AC induction motors.	47%
Room Air Conditioners	Variable-speed compressor	35%
Lighting-Incandescent	14 LPW incandescent goes to CFL (electronic ballast) at 52LPW	73%
Lighting-Reflector	15 LPW goes to CFL (electronic ballast) at 52 LPW	71%
Lighting-Touchier	Assuming 80%, incandescent at 14 LPW goes to CFL at 52 LPW, and 20% CFL stays the same	69%
Electric Water Heaters	Heat pump	50%
Refrigerators	Assuming 85% standard-size at 587 kWh AEU with savings of 51% and 15% compact at 331 kWh AEU with savings of 75%	53%
Clothes Washers	Brushless DC permanent magnet (BDCPM) variable speed	30%
Ceiling Fans	BDCPM variable speed system	30%

The integration of DC sources to conventional AC system necessitates the introduction of DC-AC converter at the generation end, thereby adding conversion losses and complexity [11]. In last two decays, the continued development of DC technologies to produce an energy efficient DC appliance is a cause of significant decrement in the building load but insists on introducing AC-DC converter, and increase the conversion

loss and complexity of the system [12]. The details of the voltage and power ratings of the DC-appliance and their AC-DC converters efficiency to connect these appliances to the conventional AC system can be found in Table 15.4. The AC-DC converter efficiencies vary from 78 percent to 90 percent according to Table 15.4. It can be noted that higher the converter power rating is, the higher is the AC-DC efficiency, as the highest efficiency 90 percent, which is in the case of a hybrid car with a converter power of rating 3,000 Watts. The cell phone converter of 4-watt power rating has the lowest efficiency of 78 percent, as mention in Table 15.4.

Table 15.4. Description of DC Appliances and Their AC-DC Converter in India

Appliance Name	Voltage Rating (V)	Current Rating (A)	Power Rating (W)	AC-DC Converter Efficiency (%)
LED Bulb	12 V	0.6	7	79
CFL Bulb	12 V	1.0	12	79
Electric Geyser	96 V	10.5	1,000	89
Sandwich Maker	24 V	23.0	550	87
Water Purifier	24 V	0.5	11	79
Refrigerator	24 V	3.0	72	87
Coffee Maker	12 V	11.0	135	87
Washing Machine	24 V	3.0	70	86
Water Pump	24 V	14.9	350	87
Vacuum Cleaner	12 V	8.0	95	87
Air Conditioner	24 V	33.3	800	88
Hybrid Car	96 V	32.0	3,000	90
Cell Phone	12 V	0.3	4	78
Ceiling Fan	12 V	1.7	20	83
Hair Drier	24 V	15.0	425	87
TV	12 V	2.5	30	83
Computer	12 V	14	170	87

15.6 Comparison between AC and DC residential buildings

A grid-connected residential building consists of DC appliances for AC and DC distribution system is shown in Figure 15.7 and Figure 15.8 respectively. The building is supplied by the public utility (PU) and PV in both cases. The energy storage (BB and EV) is used to store the energy to supply the future load in case the PV and PU are not acting. Additionally, the ES is also responsible for storing the surplus power produced by the PV and supply the surplus load to balance the power in the system in case of PU acts as outage source. The residential building consists of six rooms. The electrical specifications of the

loads are mentioned in Table 15.4. The voltage ratings of the appliances are 12 Volts, 24 Volts and 96 Volts for the low, medium and high power rating loads. As the building appliances have a wide range of voltage levels, the bipolar type of distribution system is used in order to optimise the conversion stage in the building.

15.7 AC Residential Buildings

In this case, each line has a single voltage level of 230 V AC. The DC compatible loads are more efficient than the AC compatible load [11]. Therefore, it is also assumed that each appliance is DC compatible, which helps to reduce the building load compared to the AC compatible load.

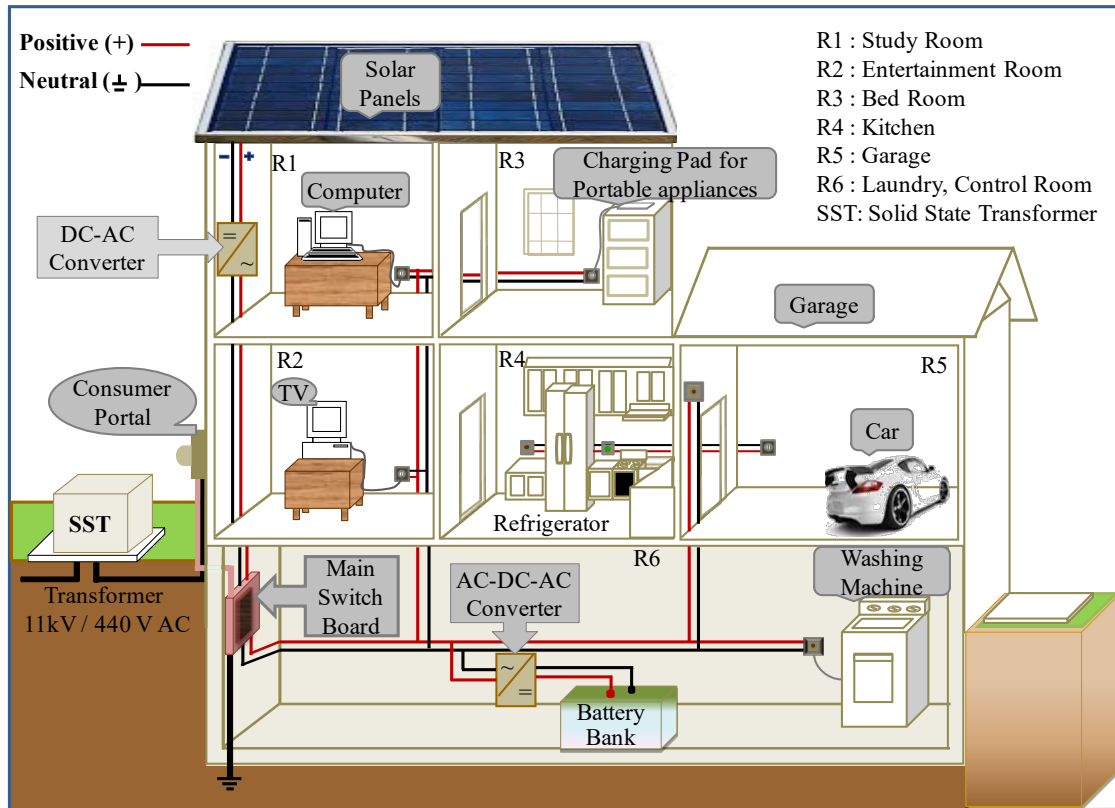


Figure 15.7. Conceptual Layout of AC Residential Building.

Moreover, each appliance has its own internal AC-DC converter to connect to the AC line, which is the cause of additional power losses. The specifications of the appliances and their converter efficiencies are given in Table 15.4. The total power consumption in buildings with ACDS (P_{ACB}) is the combination of power consumed by appliances (P_A) and power loss (p_C) in the converters. The power equation can be expressed as:

$$P_{ACB} = P_A + p_C \quad (15.9)$$

The power consumption by the appliances can be expressed as:

$$P_A = \sum_{j=1}^{j=n_a} P_{aj} \quad (15.10)$$

where P_{aj} is the power consumed by the j -th appliance.

The total power loss (p_C) in the converters is the addition of power loss in the internal converters of the appliances (p_{ac}) and the power loss in the source converter (p_{sc}) and can be expressed as:

$$p_C = \sum_{j=1}^{j=n_a} p_{acj} + \sum_{j=1}^{j=n_s} p_{scj} \quad (15.11)$$

where n_a is the number of appliances, and n_s number of source converters.

15.8 DC Residential Buildings

In this case, it is also assumed that each appliance is DC compatible which helps to reduce the building load compared to the AC compatible load. The main DC bus has 24 Volt voltage level. Moreover, one boost DC-DC converter to increase the voltage level from 24 Volts to 96 Volts and supply EV and electric geyser. A DC-DC buck converter is used to tie 24 Volts to 12 Volt DC bus. The appliances of 12 Volt ratings, such as CFL, LED, computer, TV, etc. are directly connected to the 12 Volt DC bus while for the remaining 24 Volt rating, appliances are also connected to the 12 Volt DC bus between the conductors of positive and negative polarity as shown in Figure 15.8.

The total power consumption in the buildings for DCDS (P_{DCB}) is the addition of power consumed by appliances (P_A) and power losses in DC-DC and AC-DC converters (p_c). The power expression is as given below [8]:

$$P_{DCB} = \sum_{j=1}^{j=n_a} P_{aj} + \sum_{j=1}^{j=n_c} P_{cj} \quad (15.12)$$

where $n_c = 3$, the number of converters in buildings with DCDS.

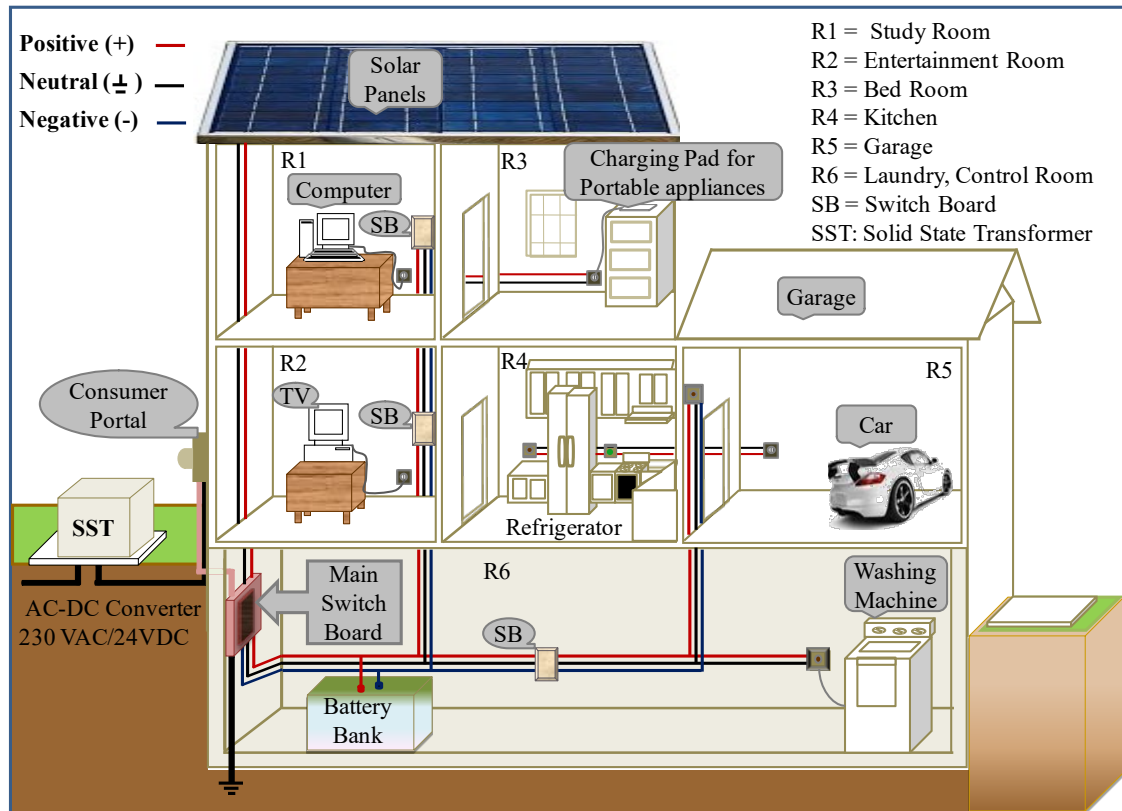


Figure 15.8. Conceptual Layout of DC Residential Building.

15.9 Automation Architecture for Smart DC residential buildings

The building automation system is where centralised control and monitoring of the building services are done. The purpose of the automation system is to maintain the building environment more efficiently to reduce the building's environmental impact and energy costs. There may be different types of architecture for the building automation. A general architecture having all type of complex activities and facilities has been shown in Figure 15.9, and it can be divided into the following levels [13]:

15.9.1 Field Level

The control and detection of the devices consist of this level. These devices may be sensors, actuators, light or smoke detectors, valves, switches and other intelligent sensors.

15.9.2 Field Network

It is the connection network between the field level and automation level. The main purpose of this network is to connect the field level devices to an RTU (remote terminal unit), in the automation level. These connections may be of four types:

- (i) Hardwired
- (ii) Bus system

- (iii) Powerline
- (iv) Wireless

15.9.3 Automation Level

This level has different advanced controllers to control and regulate the sensors, actuators and other types of field level devices. Usually, the digital-based microprocessor is used to freely program them with different control and control logic like proportional control, integral control, differential control and any other logic control as well as a combination of logic controls, etc. [14]. The controllers include the RTU.

15.9.4 Primary and Secondary Network

Most building automation networks consist of a primary and secondary bus which connects high-level controllers with lower-level controllers, input/output devices and user-interface devices. The ASHRAE's open protocol BACnet or the open protocols LonTalk specify how most such devices interoperate. Modern systems use the simple network management protocol (SNMP) to track events, building on decades of history with SNMP-based protocols in the computer networking world.

The primary network is the management network, and it is the backbone of the system. The primary network connects the automation level and the management level in the building automation system. A primary network can either be separated or shared with the conventional local area network (LAN) in a building.

Secondary networks connect the automation level and the primary network as a sub-network to the primary network. The purpose of this level is to connect the device to the automated level, but these devices are working with a different protocol compared to the devices connected to primary network devices directly.

15.9.5 Management Level

It is the level that having the capability to manage activities and monitor the building automation system. The interaction method may be personal or with the internet. Some examples of these devices are databases that log activity, web servers, operator's panels, central control station (CCS) and servers that translate messages into different protocols.

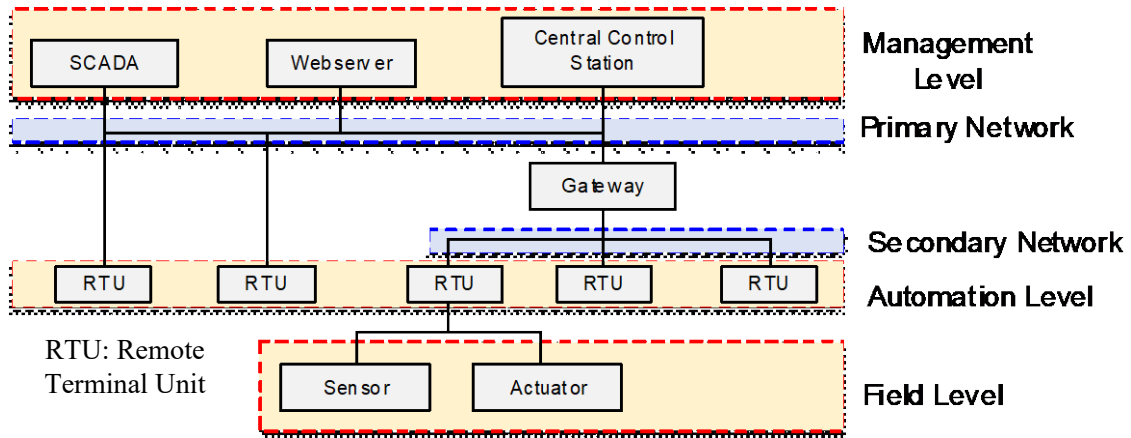


Figure 15.9. The basic network architecture of a building automation system.

15.10 Advantages, Challenges and Barriers of Smart DC residential buildings

Some factors will always be there to make the candidature of DC systems more strong than the AC system such as [15] (i) DC systems have renewable energy sources, like photovoltaic (PV) panels and fuel cells (FC), and energy storage systems, as batteries (ii) around 50 percent less energy consumption of the complete load that appears in the AC system in some operating point (iii) The scope of the integration of new sources like electric vehicle will increase the use of DC devices (iv) Zero skin effect makes the DC systems more efficient than the AC systems (v) Use of DC devices, sources and storage to interconnect and distribute the energy between them avoid the DC-AC and AC-DC conversions stages and reduces the losses.

A detailed discussion and analysis of LVDC are required to see the potential of DC technology. However, some advantages of its already are being discussed. There are various advantages including the system efficiency improvement and energy saving in the residential building. In [16, 17], a study of the US-based region was carried out with different topologies and at various locations of the country [16]. Different topologies have been considered with or without some energy storage system. The results of this study show that the efficiency is significantly improved with the storage device. Annual 5 percent energy savings are estimated without storage system, and 14 percent energy saving is observed with energy storage system. This difference in energy saving is because of the consequence of PV generation and consumption time according to the residential load. The consumption peaks in the afternoon and evening while the peak PV generation is in the afternoon. Because of this reason storage system is required to store the excess energy that is available during the peak PV generation, and utilised during high

peak demand. There are some more studies that are showing to achieve little more energy saving up to 25 percent energy saving [18, 19]. The building loads, which are affected by environmental conditions such as cooling or heating need to be considered for such type of studies. Another condition of comparison is that the AC or DC comparable loads have to consider for the different AC or DC distribution systems that have to be compared [20]. One important consideration is also that energy saving should not be considered which is achieved with extremely efficient DC loads in place of AC loads.

As several advantages and features of DC distribution system are discussed, it also faces critical challenges and some barriers when going to implement it into residential buildings. There are some challenges and obstacles to the DC distribution network:

- There is a lack of proper standardisation and codes for the DC system. However, continuous work is going on in this area. The leads, in this directions, are taken by some organisations like IEEE, the International Electrotechnical Commission (IEC), Emerge Alliance (EA), the European Telecommunications Standards Institute (ETSI), and others are already actively developing the necessary regulation and standards. However, much work is required in this direction.
- Protection schemes for the use of DC systems have to be developed. New protection devices have to be designed for the safe use of DC systems [4, 21, 22].
- Currently, there are fewer industries and devices available those will work well for the DC distribution systems. There are some rare products available when going to analyse the DC systems for residential buildings; there is a lack of products which can be used on DC voltage directly. However, there are many DC devices that can be used directly on the DC voltage as having internal conversion unit [4, 22].

In respect to energy efficiency and the fulfilment of demand DC systems taking ahead with AC distribution systems. However, for residential use, there needs to be more time is needed in order to use it in residential buildings safely with proper standards. Lack of standards, regulation methods and protection schemes are the main challenges that need to be discussed.

15.11 Comparison AC and DC residential buildings: An Illustrative example

To investigate the performance of electrical distribution system: a low voltage direct current (LVDC) distribution network for a residential building supplied by photovoltaic

(PV) including a battery bank (BB), and the public utility (PU) has been simulated in MATLABTM. The 24 Volt BB is configured with the series and parallel combination of 16 cells of 150 Ah. The 1.44 kW and 2.28 kW with a 24 Volt rated voltage PV is considered for the DC distribution system (DCDS) with DC compatible appliances (DC residential building), and AC distribution system (ACDS) with AC compatible appliances (AC residential building) respectively. The PU is tied to the consumer portal via AC-DC converter and a step-down transformer (solid state transformer, SST) to 24 Volt DC bus and 230 Volt AC for AC and DC residential building respectively. The distribution lines of the power system are considered as lossless. The power consumption in the AC and DC residential building is shown in Figure 15.10.

In the case of DC residential building, the building demand curve consists of power consumption in the DC compatible appliances of the building and power loss in PU inverter and it is represented by the blue line in Figure 15.10. In the case of AC residential building, the building demand curve consists of power consumption in the AC compatible appliances of the building, power loss in the internal converter of appliances, power loss in the BB and PV converter as represented in Figure 15.10 by the red line. The building demand always remains higher for AC residential building compared to the DC residential building.

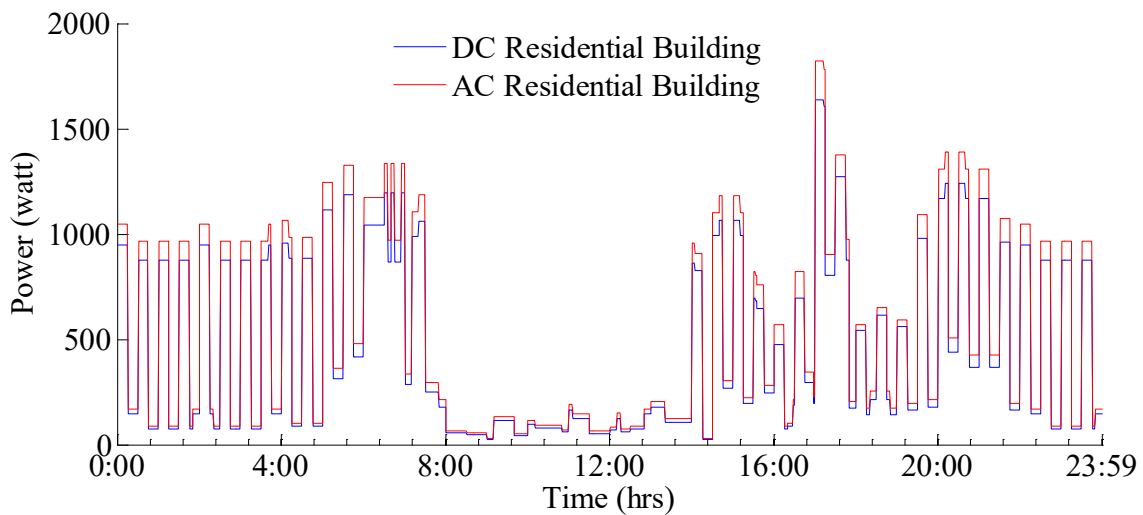


Figure 15.10. Demand for AC and DC residential building.

The PU and PV power curve for AC and DC residential building are shown in Fig.15.11. The PU and PV power curve remains always lower for the DC residential building compared to the AC residential building. Different operation modes are discussed (Mode I-Mode III)

Mode I (PU as a Source): The PU supplies the building load during the 0:00-03:00 hrs and 21:30-23:59 hrs time interval. In the case of AC residential building, all the building loads are DC compatible and connected via AC-DC internal converters. The converters loss is the combination of power loss in the internal converters of the switch ‘ON’ appliances and power equation can be expressed as:

$$P_{pu}(t) = \sum_{j=1}^{j=n_{ao}} \{p_{aj}(t) + p_{acj}(t)\} \quad (15.13)$$

where $P_{pu}(t)$ is the PU power at the time instant t , $P_{aj}(t)$ is the power consumption in the j -th appliance, and n_{ao} is the number of switched ‘ON’ appliances in the building, $p_{acj}(t)$ is the power loss in the internal converter of the j -th appliance.

Moreover, in the DC residential building, all the building loads are DC compatible and directly (without any converter) connected to the ± 12 Volt bipolar DC distribution system. The load is connected to the PU via AC-DC converter. So the power loss in the converter is the power loss in the PU converter. The power equation can be expressed as:

$$P_{pu}(t) = \sum_{j=1}^{j=n_{ao}} p_{aj}(t) + \sum_{j=1}^{j=n_s} p_{scj}(t) \quad (15.14)$$

where $p_{scj}(t)$ is the power loss in the j -th source converter, n_s is the number of power source converters.

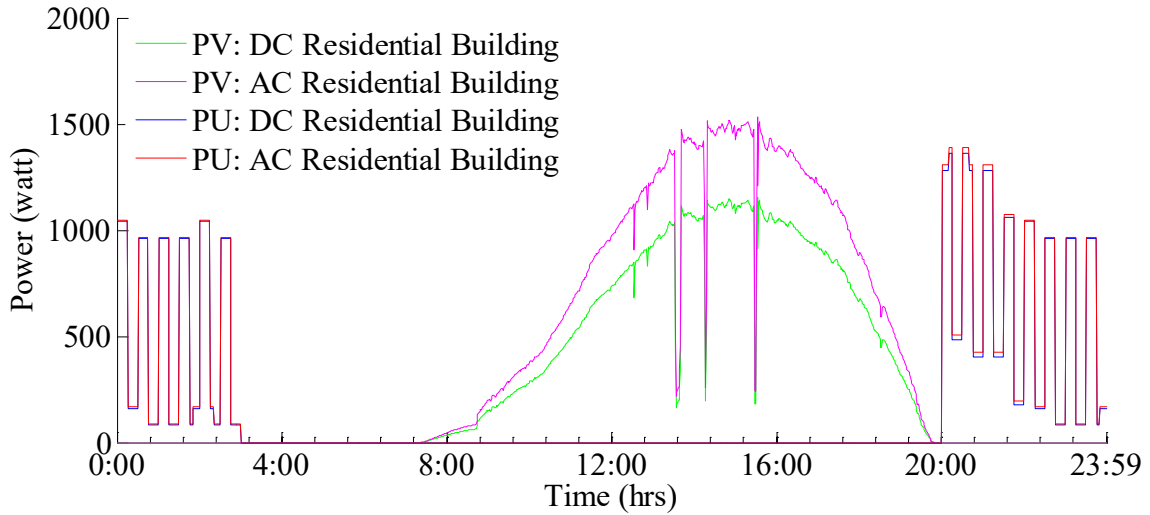


Figure 15.11. Power consumed from PV and PU in AC and DC residential building.

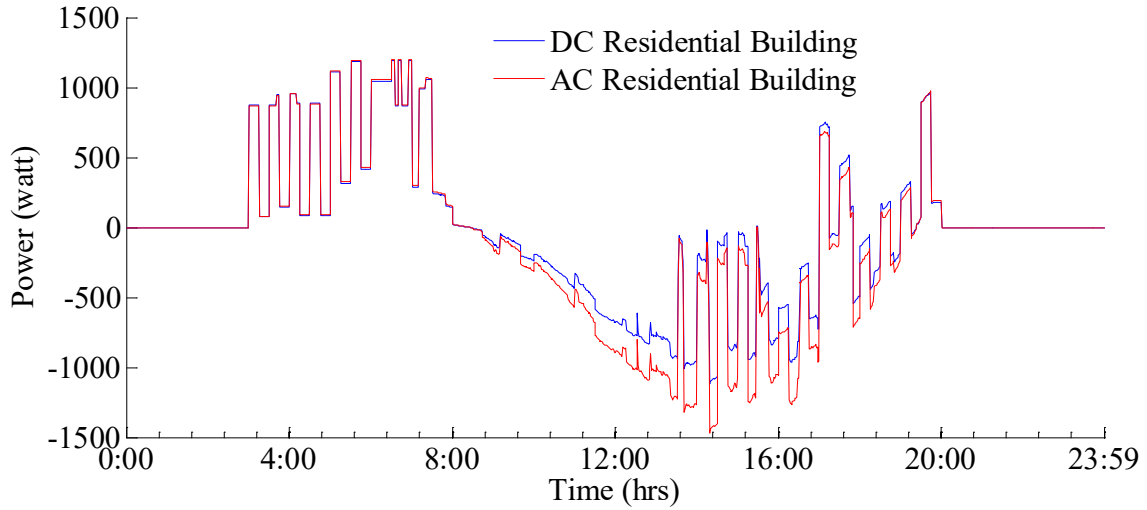


Figure 15.12. Battery bank power in AC and DC residential building

Mode II (BB as a Source): The BB supplies the building load during the 03:01-07:21 hrs and 19:51-20:00 hrs time interval. In the AC residential building, all the building loads are DC compatible and connected via AC-DC internal converters. The converters losses are a combination of power loss in the internal converters of a switch ‘ON’ appliances and the BB inverter. The power equation can be expressed as:

$$P_{bb}(t) = \sum_{j=1}^{j=n_d} [P_{adj}(t) + p_{adj}(t)] + \sum_{j=1}^{j=n_s} p_{scj}(t) \quad (15.15)$$

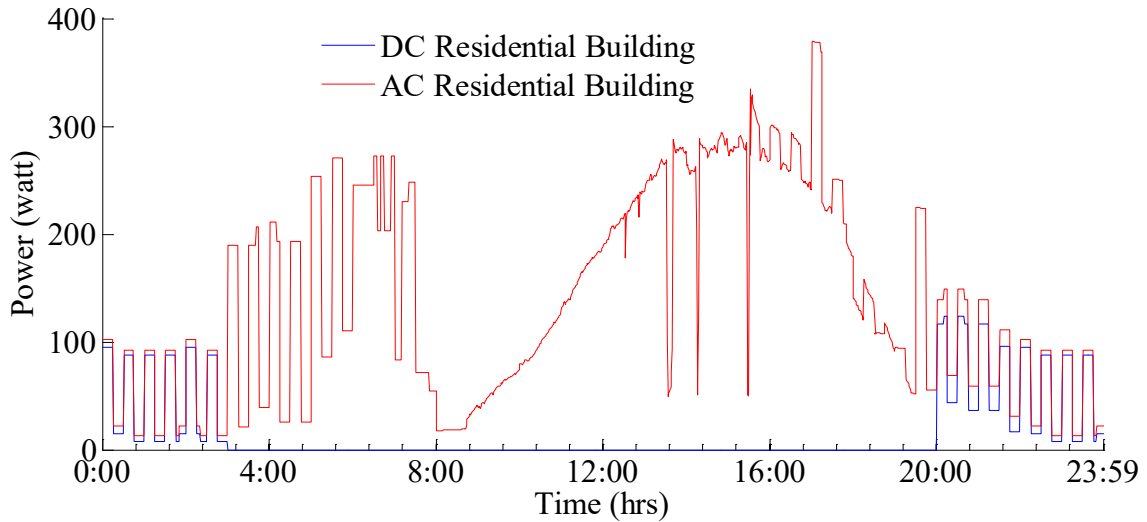


Figure 15.13. Conversion losses in AC and DC residential building

In the case of DC residential building, all the building loads are DC compatible. The appliances and DC power source (i.e. BB) are directly (without any converter) connected to the DC bus. Therefore, the power loss in the sources converters and internal converter of the appliances remain zero in this mode as represented by a green line in Figure 15.13 and Figure 15.14 respectively. The power equation can be expressed as:

$$P_{bb}(t) = \sum_{j=1}^{j=n_a} P_{aj}(t) \quad (15.16)$$

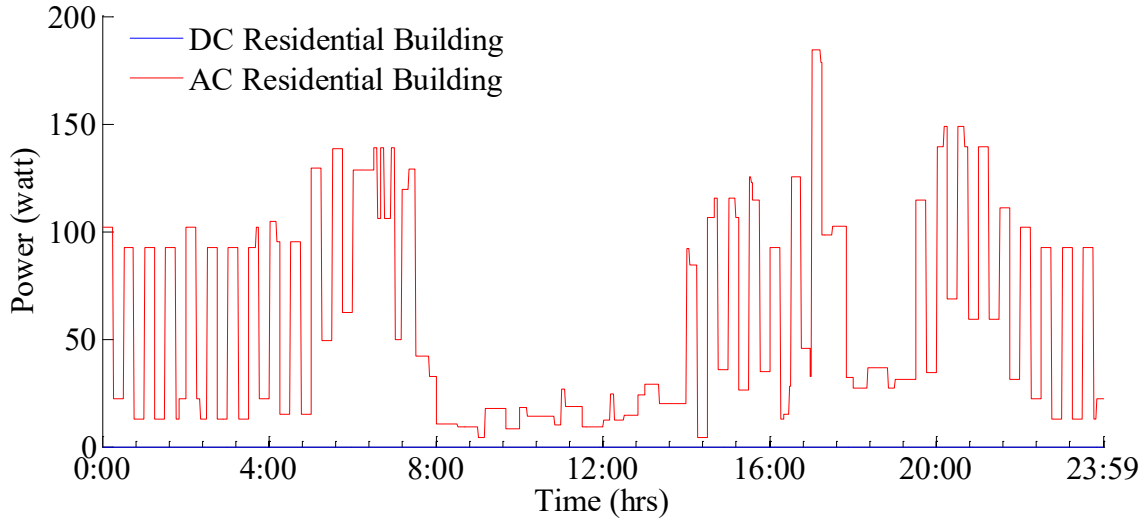


Figure 15.14. Conversion power losses in internal converters loads in AC and DC residential building

Mode III (BB and PV): The PV generates the power during the 07:22-19:50 hrs time interval. The BB balances the power by supplying the surplus load and absorbing the surplus PV power. In the case of AC residential building, all the building loads are DC compatible and connected via AC-DC internal converters. The converter losses are the combination of power losses in the internal converters of a switch ‘ON’ appliances including with PV and BB inverter. The power equation can be expressed as:

$$P_{pv}(t) \pm P_{bb}(t) = \sum_{j=1}^{j=n_a} [P_{adj}(t) + p_{adj}(t)] + \sum_{j=1}^{j=n_s} p_{scj}(t) \quad (15.17)$$

In the case of DC residential building, all the building loads are DC compatible. The DC appliances and DC power source (i.e. BB and PV) are directly connected to the DC bus without any converter. Therefore, the power loss in the source converters and internal converter of appliances remains zero in this mode as represented by the green line in Figure 15.13 and Figure 15.14 respectively. The power equation can be expressed as:

$$P_{pv}(t) \pm P_{bb}(t) = \sum_{j=1}^{j=n_a} P_{aj}(t) \quad (15.18)$$

The energy consumption, conversion losses, including energy supplied by PV and PU can be found in Table 15.5. The energy demand and conversion loss for the AC residential building are higher than the DC residential building. The conversion losses in the AC residential building is approximately 7.5 times higher than the conversion losses in the DC residential building.

Table 15.5. Description of Energy Consumption in the Building

System	Demand (kWh)	Conversion Loss (kWh)	Total Energy Consumption (kWh)	PV Energy (kWh)	PU Energy (kWh)
AC residential building	12.47	3.34	15.81	11.38	4.43
DC residential building	11.12	0.44	11.56	7.2	4.36

15.12 Conclusions

In this chapter, the concept of DC microgrid for the residential buildings has been discussed. Comparison of AC vs DC system and DC microgrids architecture has been discussed. The distribution topologies discussed in this chapter are very helpful to understand the most efficient way of interconnection. The data of energy dissipated in DC appliances and the cable cost data representing are used to show the correlation of different parameters associated with the losses. This chapter demonstrates different configurations for both the AC distribution system and DC distribution system. A power system control strategy based approach is used for the voltage standardisation. This approach enables the development of energy efficient economy and flexible LVDC system and as well as medium voltage standardisation. A comparative analysis of AC and DC residential building shows the superiority DC residential building, in respective energy saving. Simulation results also show that the power consumed in the DC residential building is less than the power consumed in the AC residential building. As the converter stages and conversion losses are much less in the DC residential building compared to the AC residential building.

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