DC Home Appliances for DC Distribution System

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ABSTRACT

This paper strengthens the idea of DC distribution system for DC microgrid consisting of a building of 50 apartments. Since the war of currents AC system has been dominant because of the paucity of research in the protection of the DC system. Now with the advance research in power electronics material and components, generation of electricity is inherently DC as by solar PV, fuel cell and thermoelectric generator that eliminates the rectification process. Transformers are replaced by the power electronics buck-boost converters. DC circuit breakers have solved the protection problems for both DC transmission and distribution system. In this paper 308V DC microgrid is proposed and home appliances (DC internal) are modified to operate on 48V DC from DC distribution line. Instead of using universal and induction motors in rotary appliances, BLDC (Brushless DC) motors are proposed that are highly efficient with minimum electro-mechanical and no commutation losses. Proposed DC system reduces the power conversion stages, hence diminishes the associated power losses and standby losses that boost the overall system efficiency. So in view of all this a conventional AC system can be replaced by a DC system that has many advantages by cost as well as by performance.

Key Words: DC Micro Grid, DC Appliances, Brushless DC Motors.

1. INTRODUCTION

In late the 1880s, the war between two rivals in favor of AC and DC power was won by the AC because of the lack of technologies in DC system. Carbon emissions coexist with the generation of AC by traditional dominant fossil fuels that seriously not only balancing out the earth environment but may also be a cause of the extinction of earth species. In DC distribution system with DC sources and DC appliances, 47% energy saving is observed by Gholase and Fernandes [1] and 22% system efficiency is improved by Anand and Fernandes [2]. In this paper system efficiency is improved by removing conversion stages and replacing induction motors with efficient BLDC motors. Keeping an eye over the present rate of research on DC, future is pro to DC technology. A typical DC distribution system is shown in Fig. 1. Such stand-alone DC distribution systems are flexible enough to integrate with other distributed generations [3].

Most appliances work internally on DC power; they take AC as input and after conversion process bring the required DC voltage level. Garbesi et. al. [4] 33% energy

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saving is estimated by replacing standard technology with the DC internal efficient appliances and a further 14% by operating DC internals on direct DC. These DC internal appliances take AC as input followed by AC/DC converter. This conversion process creates heat losses both in working mode and standby mode. If these appliances are fed with solar PV power, transformer and rectifier would be terminated from the circuit [5] that saves a considerable amount of energy [6].

The absence of skin effect in DC system [7] reduces the material cost of the wiring as the whole cross section carries the current. The overall cost of the system is greatly reduced as the equipment for the power factor improvement, AC/DC and DC/AC conversion and reactive power compensation is not required in DC distribution system [8]. Enhanced energy savings and improved reliability by DC distribution system is recommended by Vagelis et. al. [9]. Soo and Jung [10] have studied the efficiency of the DC distribution system by using multiple DGs (Distributed Generations) while Kamran et. al. [11] has studied MPPT based DC-DC buck-boost converter for multiple DGs.

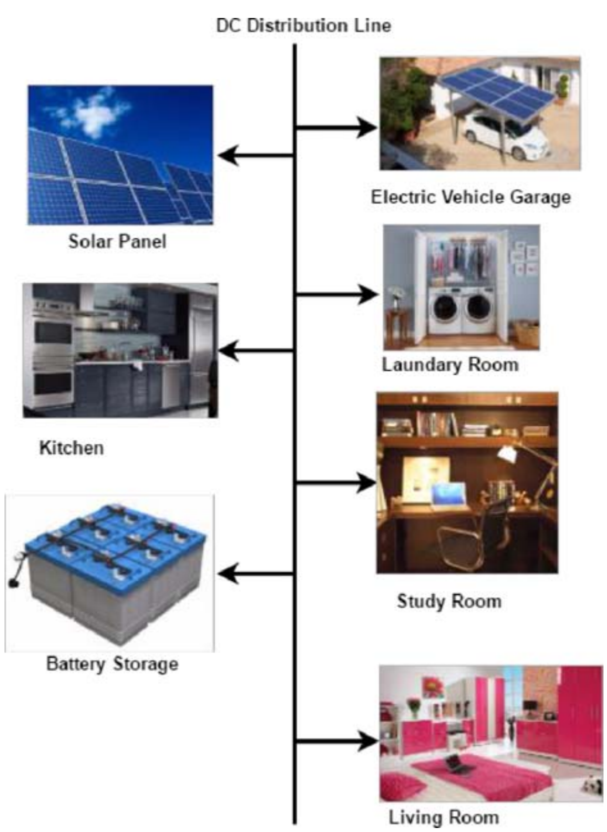

FIG. 1. SHOWING THE LAYOUT OF DC DISTRIBUTION SYSTEM

With the advancement in semiconductor materials and devices DC can directly be generated by using solar PV cell. Solar PV cell generates clean and green renewable energy. Historically, this energy is either stored in batteries or delivered to the AC grid through inverters that brings major conversion losses.

2. EFFICIENCY IMPROVEMENT OF DC SYSTEM

The efficiency of a DC distribution system depends upon the losses in the cables and conversion losses (power electronics + electro-mechanical conversion stage) as given by Equation (1).

$$P_{loses} = P_{cables} + P_{converter} + P_{mechanical} \quad (1)$$

P_{cables} are the losses occurring in the distribution cables. They depend upon the voltage level of the distribution line. In this paper 308 V DC, the peak value of 220V AC, is selected as a distribution line voltage since the voltage level below this increases the losses in cables as given in **Table 1** calculated by Equation (2) [12].

$$P_{cables} = \left(2.\frac{\rho}{A}\right)\left(\frac{P}{\eta.NV_{DC}}\right)^2 .2l\left(\frac{N^2+2N+2}{6}\right) \quad (2)$$

TABLE 1. LOSSES AT DIFFERENT VOLTAGE LEVELS

Voltage (V)	Losses (W)
308	17.19
220	33.7
110	134
48	708

Where ρ is the electrical resistivity ($2x10^{-8}$ Ω.m), A is the X-sectional area of cable ($60mm^2$), l is the total length of the cable (200m), P is the total power that load absorbs (100 W assumption for each apartment), η is the converter efficiency (85% assumed), V_{DC} is the DC distribution line voltage level, N is the number of apartments in the building that is assumed 50 in this paper.

$P_{converter}$ are the losses that occur in the converter. They are in inverse relation with the efficiency of the converter as given in Equation (3) [12].

$$P_{converter} = \left(\frac{1}{\eta}\right)P \tag{3}$$

Efficiency (η) of the DC-DC converter is higher than DC-AC-DC because of the double conversion in the latter converter [13]. This is one of the reasons that DC home appliances operated on DC from DC distribution line are proposed here.

$P_{mechanical}$ are the losses that occur in the conversion of electrical power into mechanical power as in motors. DC motors and 1-θ induction motors are not efficient enough to boost the efficiency of the proposed DC distribution system. Replacement of these motors with the BLDC motors is proposed in this paper.

3. DC HOME APPLIANCES

Not all but most of the home appliances internally operate on DC that is obtained after a transformer and a rectifier constituting a major part of the power losses. Anand and Fernandes [2] stated a 22% reduction in resources if we use DC than conventional AC for residential loads and it is safe and sound for human even in direct touch. This portion discusses the modified 48V DC appliances in which transformer and rectifier are replaced by a DC-DC power electronics converter. These modified appliances are more efficient than traditional AC fed appliances.

3.1 Appliances with Motors

Most of the appliances having rotatory part use universal dc motors or 1-θ induction motors which have low efficiency because of carbon brush and mechanical commutation bearing a major maintenance cost and mechanical losses. All such motors can be replaced with BLDC which has a high efficiency, low noise [14], low power consumption and a wide range of speed.

In BLDC motor permanent magnet acts as a rotor while 3-θ DC supply is given to the static stator coil. There is low stator and rotor air gap which increases the efficiency by increasing the magnetic torque on the rotor by the stator. So no need of carbon brushes to supply the current which makes it maintenance free. But because of the presence of magnet, electronics and sensor, BLDC motor is costly than induction and universal motor [15]. With the adoption of DC grid and BLDC motor in industrial and residential appliances, the cost will definitely be reduced in future.

3.1.1 Air Conditioner

Conventional air conditioning units use either 1-θ induction motor or universal motor for compressor, swing and blower fans. They are fed with 220V AC and also carry some AC-DC conversion for low voltage applications as shown in Fig. 2.

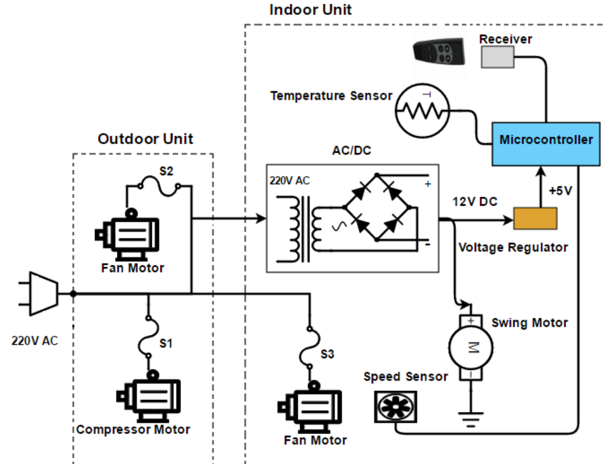

FIG. 2. CURRENT AIR CONDITIONER CIRCUIT

DC operated air conditioning units are available for automobiles that use DC compressors, DC blower fan motor and DC swing motor. In the proposed system these DC motors are replaced with BLDC motors and the AC-DC converter is replaced by the DC-DC converter. The outdoor unit takes 48V input for itself and the indoor unit's swing BLDC motor, blower fan BLDC motor and control unit. The use of BLDC motors for indoor and outdoor units reduces the noise level and energy consumption. Solar 48V AC is available by green energy innovations and hotspot energy [16,17] which can be operated on the proposed DC distribution system with the incorporation of a DC-DC converter. The proposed BLDC motor based DC operated air conditioner is depicted in Fig. 3.

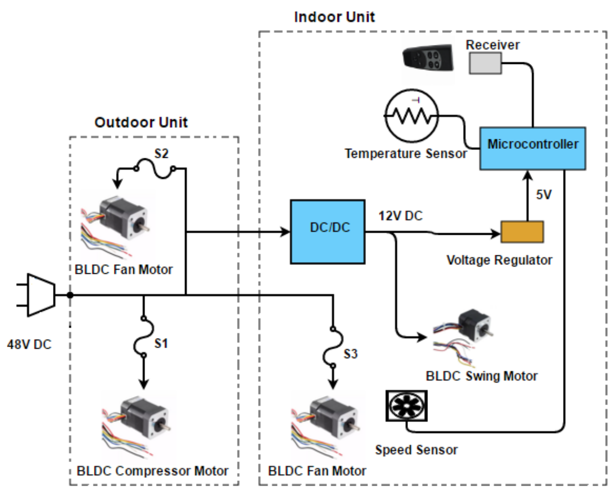

FIG. 3. FLOW DIAGRAM OF DC AIR CONDITIONER CIRCUIT

3.1.2 Microwave Oven

Microwave oven consists of two sections with separate independent circuits and power supplies. HVS (High Voltage Section) and LVS (Low Voltage Section). HVS contains magnetron whose power supply consists of a high voltage transformer followed by a voltage doubler. While LVS contains turntable motor, magnetron fan motor (1-θ induction motor) [18] and switching device. In AC operated microwave oven 220V from input AC source is supplied to the turntable and magnetron fan motor as shown in Fig. 4. In some modified ones, the 220V is stepped down to operate a 21V turntable AC motor that reduces manufacturing cost and power consumption [19].

In DC microwave oven input AC is rectified into DC using transformer and rectifier to run turntable DC motor, magnetron fan motor, lamp and switching device. Output DC voltage is inverted into AC and boosted by a transformer and again converted into DC to supply to the magnetron [20] as shown in Fig. 5.

In proposed DC microwave oven input is taken directly from a DC distribution line which in low voltage section drives the BLDC turntable motor, BLDC magnetron fan motor, DC lamp and a switching device. In HVS it is boosted by using a flyback converter and supplied to the magnetron as shown in Fig. 6. In this method conversion losses, mechanical losses and noise are greatly reduced and a high efficiency is achieved.

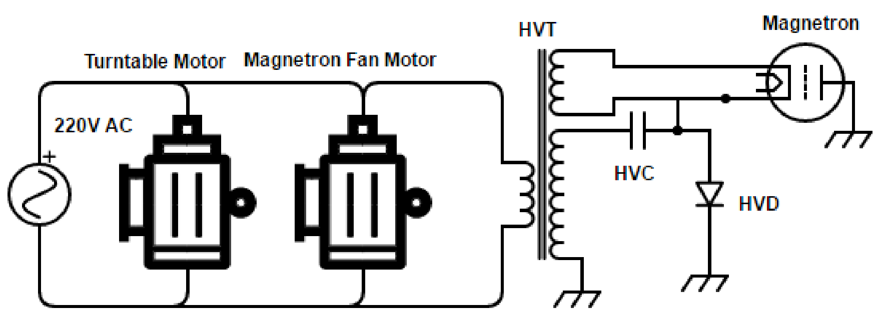

FIG. 4. AC MICROWAVE OVEN

3.1.3 DC Fans

Current ceiling, table and bracket fans use 1-θ induction motors which are heavy and inefficient with 50% efficiency [21]. Fans with DC motors take DC power after transformation and rectification of the commercially available 220V AC. These DC motors bear friction losses and brushes maintenance cost making it inefficient. Future DC fans will be popular with BLDC motors taking DC input directly from the proposed DC distribution line. Fans with BLDC motors use 50% less power which can further be reduced by improving the aerodynamics of the blades [22]. Desroches and Garbesi estimated an efficiency of 90% with 75W BLDC fan and 75% efficiency with 75W AC induction motor [23]. These fans would be highly efficient with minimum conversion losses.

3.1.4 Cloth Washer

Most of the cloth washers available in markets incorporate 1-θ induction motors. They use transformer and rectification process to obtain a DC lowlevel voltage to operate the control circuit. Fisher and Paykel have some models that use BLDC motors but incorporate a rectifier. In lieu of using AC power followed by transformer and rectifier, DC input from a DC distributed line is proposed to operate BLDC motor and control circuit of the washing machine and dryer.

3.1.5 Water Pump

Current home water pumps use a 1-θ induction motor operated on 220V AC. In solar DC water pumps for flood irrigation an inverter is used to run 1-θ induction motor.

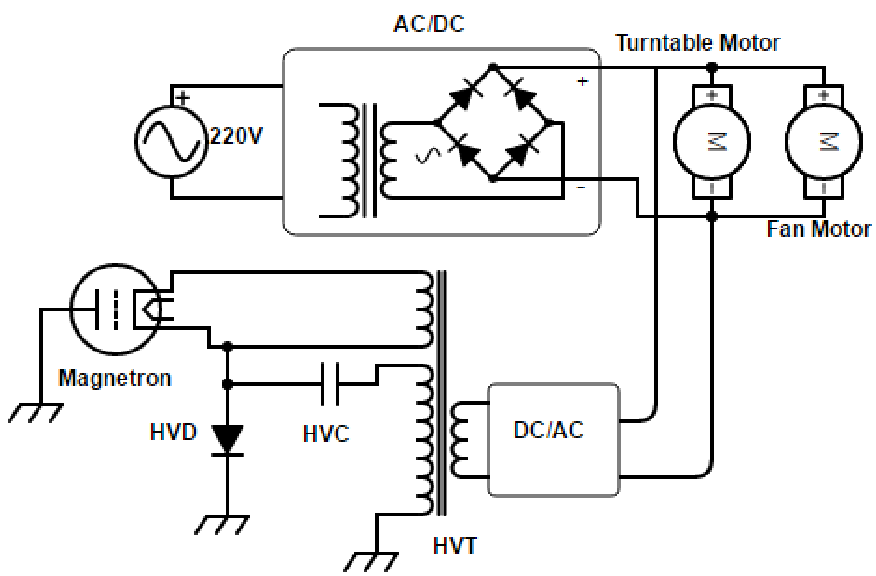

FIG. 5. DC MICROWAVE OVEN

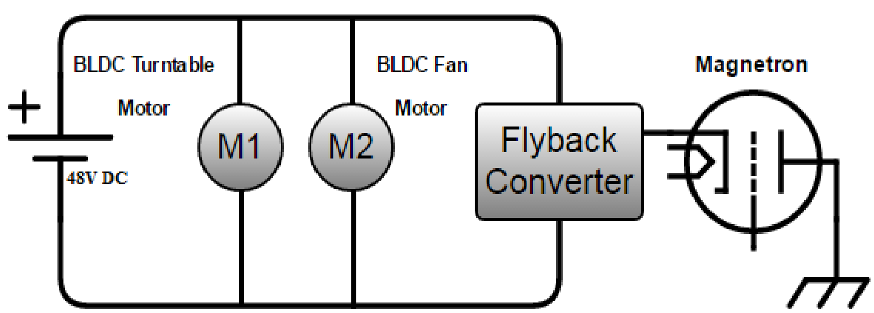

FIG. 6. PROPOSED DC MICROWAVE OVEN

This water pump can be modified into an efficient one by replacing induction motor with BLDC motor operated on 48V from DC distribution line. Some 12V BLDC pumps with low flow rate are available in the market for drip irrigation, system. Rajan et. al. [24] has proposed an MPPT based DC-DC buck-boost converter to operate a BLDC water pump from solar PV.

3.1.6 Refrigerator

Current home refrigerators use 1-θ induction motor compressor. In market 12 and 24V BLDC compressors by Zhejiang Boyard are available for mobile freezers and car/truck air conditioners. They can be used in home refrigerators and 48V BLDC compressor is also available for heavy applications. Such refrigerators can be operated at 48V from DC distribution line proposed here. The universal motor used for condenser fan motor is also replaced with BLDC fan motor. The replacement of AC motors with BLDC terminates most of the conversion stages improving system efficiency.

3.1.7 Air Cooler

In air cooler 3 motors are used. 1-θ induction pump motor, 1-θ induction fan motor and a swing motor. In proposed air cooler all these motors are replaced with BLDC motor. In solar air cooler DC power is inverted to AC which is eliminated in the proposed system.

Various appliances like automatic door system, dish washer and mixer grinder running with DC motors are available in the market that need only the replacement of universal motor with BLDC motor and AC/DC converter with DC/DC. In [1] a DC operated BLDC mixer grinder is proposed with the efficiency of >80%. While the current universal motor grinder has an efficiency of 43% only.

3.2 Electronics Appliances

Laptop computer, TVs, security cameras and data centers are the major electronics load which can be made efficient or even energy star just by replacing input AC/DC converter with the buck-boost converter.

3.2.1 Laptop

In current laptop adapter, 220V AC is taken from the distribution line. After stepping it down and rectification process it is decided by the switching technique whether to charge the battery or run the laptop or both. Using buck converter the output 19V DC is reduced to 5, 3.3, 2 and 1.5V for various components to operate. The power architecture is shown in Fig. 7.

In proposed scheme input is directly taken from 48V DC distribution line followed by a buck converter with the 19V output. Hence this proposed DC adapter is much efficient than current AC adapter as major power conversion losses are eliminated in proposed architecture as shown in Fig. 8.

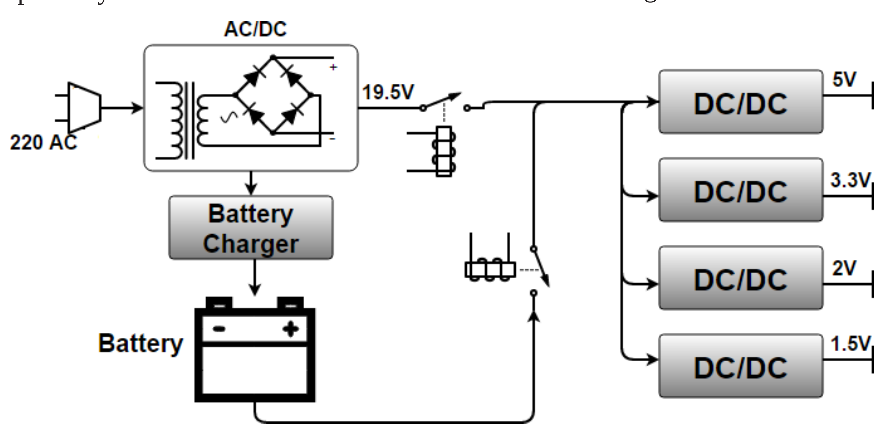

FIG. 7. CURRENT LAPTOP POWER ARCHITECTURE

3.2.2 Lights

Until now incandescent lights are widely used in residential areas. These are highly inefficient because of their resistive nature. Compact Fluorescent CFL replaced the incandescent light because of high efficiency. The reason of inefficiency is again the power conversion stage from AC-DC and old technology. LED (Light-Emitting Diode) lights are the most efficient one with low energy consumption and long operating life. They best work on the DC distribution system resulting highly efficient. LED converts 80% of the input energy into light as compared to 10% of the incandescent bulbs [25]. Table 2 shows that LED consumes less power as compared to old technologies and average life is much larger.

3.2.3 LED television

In AC fed LED TVs, input AC is passed through EMI filter, transformer followed by a rectification stage and a PFC (Power Factor Correction) stage to take the input line PF close to unity. A DC-DC flyback converter is used to operate CCFL and standby power stage shown in Fig. 9. These conversion losses can be eliminated if LED TVs are operated directly on DC distribution line as shown in Fig. 10.

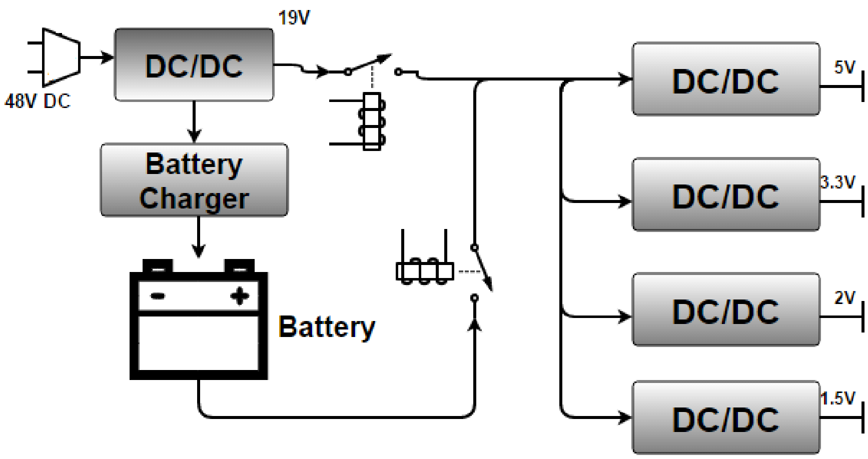

FIG. 8. PROPOSED LAPTOP POWER SCHEME

TABLE 2. COMPARISON OF LIGHT TECHNOLOGIES [19]

	Incandescent	CFLs	LEDs
Watts Consumed	75	20	16.5
Average Life (hours)	1000	10,000	25000-35000
Average Cost/bulb $	0.50	5	25-100
Operating Cost/yr $	8.87	2.37	1.95

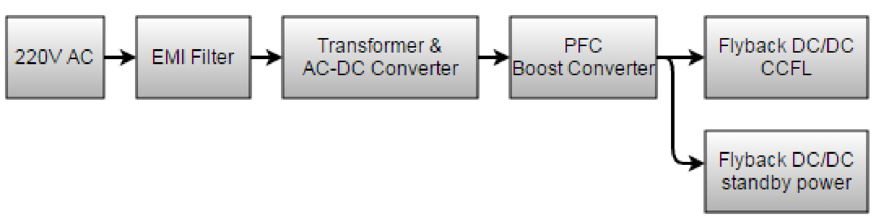

FIG. 9. AC OPERATED DC INTERNAL LED TELEVISION

The power consumption of different television technologies of different screen sizes is given in Table 3. From Table 3 it is obvious that LED TV is the most efficient one which can further be improved by excluding rectification stage proposed in Fig. 10.

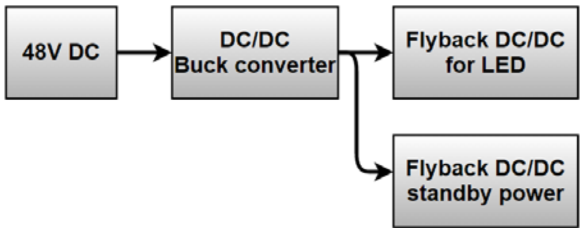

FIG. 10. DC OPERATED LED TELEVISION

TABLE 3. POWER RATINGS OF DIFFERENT TV TECHNOLOGIES [26]

Screen Size (Inch)	LED	LCD	CRT
15	15	18	65
17	18	20	75
19	20	22	80
20	24	26	90
21	26	30	100
22	30	40	110
24	40	50	120
30	50	60	-
34	55	70	-

3.3 Reduction in Power Consumption

In order to estimate the energy savings by adopting a DC distribution system, power ratings of different home internally DC appliances taking AC as input are collected from [4]. AC-DC power conversion losses are calculated by using Equation (3). Then a load profile for a family of 3 members for a month is calculated using calculator [27] and it is observed that 65.4 kWh/month/home energy can be saved if the internally DC appliances are operated directly on DC as shown in Table 4.

The other advantage of removing AC-DC converter is the savings of standby electricity which is consumed even the device is switched off but still plugged in standby power of different appliances is given in Table 5 [18] and it is estimated that 22.6 kWh/month/home energy can be saved by the proposed DC home appliances in this paper.

Efficiencies of different AC and BLDC motors for various home appliances are collected from [1,21,22,28] and it is estimated that an overall 24% efficiency of the system is improved by replacing AC motors with BLDC motors shown in Table 6.

TABLE 4. ENERGY SAVINGS AVAILABLE IN CONVERSION STAGES

Appliances	DC Internal Power (W)	Conversion Efficiency AC/DC	Conversion Losses (W) AC/DC	Quantity	Working Hours	DC Internal	Direct DC (kWh)
Ceiling Fan	88	0.87	13	3	180	54.5	47.5
Room AC	1900	0.89	235	1	90	192	171
Clothe Washer	350	0.87	52	1	6	24	21
Coffee Makers	900	0.87	134	1	4	4.1	3.6
Color TV	175	0.85	31	1	60	12.36	10.50
Dishwashers	1200	0.88	164	1	15	20.46	18
Clothes Dryers	2790	0.89	345	1	2	6.27	5.58
space heater	1000	0.89	124	1	60	67.44	60
Freezers	540	0.87	80	1	720	44.64	38.88
Incandescent	30	0.84	6	3	150	16.2	13.5
Microwave Oven	750	0.87	112	1	5	4.31	3.75
Desktop	74	0.82	16	1	60	5.4	4.44
Security System	20	0.83	4	4	720	69.12	57.60
Total						520.8	455.35

TABLE 5. STANDBY LOSSES OF APPLIANCES

Appliances	Average Standby (W)	kWh
Air Conditioner	0.9	0.648
Mobile Charger	0.26	0.187
CRT Monitor	0.8	0.576
LCD Monitor	1.13	0.814
Hub, USB	1.44	1.03
Modem, DSL	1.37	0.986
Laser Printer	1.58	1.14
Scanner	2.48	1.78
Security System	2.7	1.94
Speakers	1.79	1.29
CRT TV	3.06	2.20
CD Player	5.04	3.63
Coffee Maker	1.14	0.821
Microwave Oven	3.08	2.22
VCR	4.68	3.37
Total	31.45	22.6

TABLE 6. EFFICIENCY COMPARISON OF AC AND BLDC MOTORS FOR HOME APPLIANCES

Appliances		AC	BLDC
Microwave Oven	Turntable Motor	75	90
	Fan Motor	75	90
Air Conditioner	Indoor Fan	75	90
	Outdoor Fan	75	90
	Compressor	60	80
Refrigerator	Compressor	60	80
	Condenser Fan	75	90
Air Cooler	Pump Motor	75	91
	Swing Motor	75	90
	Fan Motor	75	90
Ceiling Fan	Fan Motor	75	90
Water Pump	Pump Motor	75	91
Elevator	Elevator Motor	75	90
Dish Washer	Washer Motor	75	90
Cloth Washer	Washer Motor	75	90
Cloth Dryer	Dryer Motor	75	90
Mixer Grinder	Grinder Motor	43	80
Average Efficiency (%)		71	88

4. CONCLUSION

This paper investigates the energy savings by adopting DC distribution system instead of conventionally dominant AC distribution system. A DC microgrid of 308V is chosen as a distribution line voltage. Home appliances are modified by removing voltage transformation and rectification and replacing 1-θ IM with most efficient BLDC motors. This increases the efficiency of the appliances and makes them compatible with the DC distribution system. The removal of AC-DC conversion saves 65.4 kWh/month/home energy from conversion losses and 22.6 kWh/month/home from standby losses. The replacement of AC motor with BLDC motor increases the overall efficiency of the system by 24%. Therefore, 308V DC distribution system with DC efficient home appliances saves a handsome amount of energy and can be envisaged as a future DC grid.

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