

# Low Voltage DC Distribution System for DC Home Appliances: A Review

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**Abstract:** Our country needs a cost effective solution to electrify many rural and remote areas. DC home is becoming a promising solution for a household in many places where main grid electricity is not accessible. For a DC home, voltage level is the important parameter which affects the performance and safety of the system. In this paper, authors present an overview on standard DC voltage levels which is suitable for residential household. The modification of various conventional appliances and switches to adapt in DC supply are also reviewed. Due to the lack of standards in DC system causes a hindrance for penetration of DC home. Based on the load ratings in Rural Indian home, the most suitable voltage levels are also discussed for both lighting loads and power loads.

**Index Terms - DC distribution, energy efficiency, DC home, energy losses.**

## I. INTRODUCTION:

Nowadays, deciding of AC or DC electrical system for residential and commercial building has brought back the battle of -War of current by Edison and Tesla/Westinghouse in 1882 [1]. With advancement of power electronics technology, the voltage level conversion can be done easily with highly efficient converters and brings cost reduction and efficiency improvement [2]. Moreover, due to the depletion of fossil fuels, energy demand and climate change necessitates the search for reliable and eco-friendly Renewable Energy Resources (RES). The RES such as solar PV, wind turbine, fuel cell have become a major target to meet the ever-increasing energy demand [3]. The integration of various RES, battery and grid to power the load demand, has become an important feature for a continuous or islanding mode power supply for microgrid [4]. As technology advances, the demand of DC source increases with various DC load such as Compact Fluorescent Lamp (CFL), Light Emitting Diode (LED), refrigerator, air conditioner, fan, laptop [5] and variable speed-motor [6]. These loads require AC to DC converter if used with AC supply and brings additional losses in the electrical system. In DC system, the number of converters required are eliminated [7] and thereby, reduces loss in the power system. Due to absence of frequency in DC system, they are free from inductance, dielectric losses, skin effect and different interference with communication system. The absence of skin effect reduces the conductor size as well as voltage drop as compared with AC system [8]. The compatibility of DC distribution system with the RES [9] and storage system is easier than AC system, since frequency is absent. The level of voltage is the only requirement to monitor while interfacing with sources and storage systems.

DC system has been in use for a long time in data centers [10] [11], ships [12], aircraft, and telephone communication [13]. However, lack of standards [14] in DC system could not put the mass production of DC equipment and appliances which put DC system at higher cost for installation. Recently, many appliances have been developed for DC system that runs mostly at 12V DC, 24V DC and 48V DC supply; but incurred more losses for power rating appliances in these levels. For efficient DC Distribution System (DCDS), the voltage level plays a major role in switching surge at high voltage and cable losses at low voltage. The various factors should be considered for choosing standard such as the rating of appliances and equipment, building architecture [15], total power consumption, safety measures, and availability of appliances in the market. In the present situation, the solution for transition from existing AC system to DC system depends on minimum modification for both equipments and appliances. The adaptation of conventional AC appliances in DC system mainly depends on some chosen DC voltage level since frequency and phase sequence are absent.

In this paper, a detail review has been done on DC voltage levels in recent researches field and available standards in international level in section II. In section III, various voltage levels are classified and advantages and disadvantages for home appliances are presented. In section IV, modification of various appliances for DC home is also presented. In section V related papers are discussed on protection scheme in DC system. Section VI, describes the chosen voltages for DC home in rural India for lighting loads and power loads in equipment point of view.

## II. VOLTAGE LEVELS IN DC DISTRIBUTION SYSTEM

Recently, lots of researches in DC micro-grid, have been performed on standard voltages to save energy in residential houses and commercial buildings. The different DC voltage levels are presented below based on recently available papers.

**a) 12V DC voltage**

In DC extra-low (12V- 60V) voltage, the integration of storage system, sources and loads can be done directly without use of complicated converters in the electrical system. In [15], Friedeman et al. (2003) proposed a system having total power rating of less than 150W and 12V DC is considered as the ideal voltage for appliances. At this voltage, the requirement of individual converters can be eliminated for each load but brings losses along the cable line due to high current. To minimize these losses, authors have suggested to optimized the architectural design of the building.

**b) 24V DC voltage**

Emerge Alliances (EA) has standardized this voltage level to supply energy to electronic and IT equipment, therefore in DC home, low power appliances in bedroom and living rooms can be supplied safely and efficiently at this voltage [16]. In [17], Williamson et al. (2011) investigated this voltage level in university library computer and reported the energy saving of 14% to 47% for appliances when the system change from AC to DC system.

Chauhan et al. (2014) have done the analysis of losses on the Total Daily Load (TDL) in DC voltages level of 24V, 48V and AC voltages of 120V, 220V and 230V with inverter efficiency of 92% of 2.4kW load rating and found that 24V DC is better than in 230V AC [18]. LabView simulation was also performed both on the proposed DCDS and ACDS for comparison.

Sanjeev et al. (2015) have selected 24V DC as DC bus voltage level and performed power consumption cost analysis for AC and DC home by considering typical Indian household loads [19]. The result showed a huge saving in DC system. Simulation results are also carried out in RSCAD RTDS software with configuration parameters and found that reliability of supply is achievable.

Sahoo et al. (2016) have made comparison of conventional 230VAC system with 24V DC system by considering two proposed models: AC home and DC home with and without solar PV panel integration based on parameters of PV power, load power, batter power and inverter losses [20]. They concluded that, the initial cost for installing of DC home was found to be little higher than that of AC system but this might be due to the lack of mass production of DC appliances.

Chauhan et al (2016) have proposed a DC distribution system for a building with 24V DC as the main voltage level. For power appliances, a boost converter is used for converting 24V DC to 96V DC and a buck converter for 12V DC appliances [8]. The power consumption of buildings is evaluated on both DCDS and ACDS based on appliances consumption and converter losses. MATLAB simulations are also carried-out for validation.

**c) 48V DC voltage**

This voltage level has being used in telecom industry since long time back [13], hence supporting appliances and devices at this voltage are available. At this voltage, the loss decreases by of that of the 24V DC for the same rating and specification.

BLDC motor also runs on 48V DC when supply from the solar panel. IIT, Madras has proposed this voltage level to address the issues in brownout situation. The voltage level of 50V DC is considered as safe for human being with direct contact up to 3 second [21].

Rodriguez et al. (2008) have modeled the conventional home appliances to adapt 48V DC supply since the renewable sources and loads are DC in nature [6]. The various home appliances are modeled to adapt to this voltage and evaluated their load profile for a month both in AC system and DC system, and found lesser power consumption in DC system.

Rosnazri et al. (2010) have developed a new hybrid system (Solar and Utility grid) to power the houses and buildings at 48V DC using an electromechanical inverter with a synchronous generator and DC motor system [22]. The proposed system has found that better harmonics isolation, power isolation, harmonic reduction, surge and transient protection, and sag protection. Simulations are also carried out using voltage and current parameters in various conditions.

Anand and Fernandes (2010) have suggested the different DC voltage levels for residential and commercial building based on system performance and safety factors [23]. The authors have concluded that 48V DC and 400V DC to be the optimum voltages level with improvement of 15-22% and 10-11% efficiency over conventional AC system for residential and commercial system respectively.

Amin et al. (2011) have made the comparison between 230V AC with 24V DC and 48V DC distribution system using cable and appliance losses. In proposed system, the cable cross-section are optimized for 48V DC based on line losses, cost of cable and found that energy consumption is the lowest at this voltage [5]. They have also suggested that more savings could be achieved by integrating with renewable energy sources and reducing the number of converters in DC system.

Shibata et al. (2011) have proposed a system on Power over Ethernet (PoE) as the physical and data-link layer protocol [24]. A prototype UTP cable is used for power transmission and communication between devices and network. The DC voltage level of negative 48V has been considered for power transmission. In this system, network acts as an intelligent device for choosing the best possible sources which gives efficient control of electricity to keep the quality of life and consumes electricity from dispersed power sources at home.

Shivakumar et al. (2015) have investigated the feasibility of DC system by comparing hybrid AC-DC system with a proposed DC system for energy saving and economic payback [25]. The transition of AC system to DC system depends on the equipment, sources and converter cost. USB 3.0 technology is considered as the main reason for transition to DC system. Voltage levels of 12V - 50V DC are considered for low and medium appliances and 400V DC for higher power rating.

Kamalakaran et al. (2016) have made the performance analysis on various home appliances with conventional motors and their counterpart motors replaced by Brushless Direct Current (BLDC) motors [26]. They have observed that the efficiency of BLDC appliances are better than the appliances with conventional motors and also the compatibility of BLDC motors with 48V solar DC system has put more flexibility in application level.

They have presented the compatibility of conventional universal motor in mixer grinder with BLDC motor [27]. The Finite Element Analysis (FEM) has been carried out for optimum designing of BLDC motor and their performance and efficiency analysis has been done in 48V DC and 300V DC. At full load and high speed conditions, the power saving is more than 50% in a mixer grinder driven by BLDC motor. Furthermore, Gholase and Fernandes (2015), have also done FEM analysis at 48V DC and found that Iron and copper losses are just 5.2% of input power in BLDC motor whereas in conventional universal motor it is 40% above [28]. Simulation result showed that surface mounted ring Permanent Magnet (PM) design has better efficiency and lower volt-amp than Interior PM design.

Prokash et al. (2016) have considered 24V, 48V, 48V with optimized cable DC voltage and made comparison with the existing 230 AC system for life span of 20 years in Bangladesh and found that 48V DC with optimized cable to be the best suited for DC home [29]. The authors have also suggested that placing of heavy power appliances near the source decreases the cable loss. In cost comparison of cable, 48V DC with optimized cable are 34.34% costlier than other systems but gives a huge saving in long run.

Rajaraman et al. (2016) have developed a solution for uninterrupted DC supply and implemented at Sasaram to supply 24X7 powers [30]. During burn-out situation the voltage reduces to 90V in the utility grid. For this situation, two devices are implemented such as Brown-Out Feeder Energization Automation Systems (BOFEAS) for controlling the transition of the feeder from normal to brown-out operation and vice-versa and Uninterrupted DC Power Module (UDPM), which interprets this low voltage signal and cuts from main AC supply. 48V DC is considered as the standard voltage for DC appliances during the brownout condition with maximum output power of 125W.

#### d) 120V DC voltage

In 120V level, the rating of power appliances can go up to 2000W without significant losses on the cable line [31]. In [32], NEN 1010 has considered this voltage level as touch safe under normal condition and the protection against the indirect contacts like expose conductive parts is not necessary but grounding is required at this voltage level. The DC voltage levels below 120V are considered as impractical for electricity distribution and IEC-60038 set 120V as extra-low voltage for DC upper boundary of extra DC low voltage [33]. The line loss is optimum and above which the line loss do not decreases substantially [34].

Li et al. (2012), have classified electrical loads into five groups for connecting to a common DC bus and also alternative path for higher power appliances from utility grid in order to minimize the conversion stages [7]. The simulation result shows 120V DC as the optimum level for home appliances based on parameters such as losses, load power and loading distance and beyond which the loss saving is not much dominant.

#### e) 220V DC voltage

The 220V DC level is adaptable to the existing building grids and also the resistance equipment of 230V AC without major modification due to the same rms level and gives advantages while transition from AC to DC system. Techakittiroj et al. (2008) have proposed an architecture of wide voltage range from 140V to 220V DC system [35]. The choosing of these range are based on ease of voltage level conversion, commonly used in UPS output voltage, universal AC voltage level and availability of circuit breakers in the market. The proposed architecture is classified into three groups as sources, sinks and bidirectional devices in which the power flow are controlled by the voltage level of terminals.

Makarabbi et al. (2014) proposed a DC system of 220V and compared with 230V AC system on its performance analysis [9]. This DC level is chosen due to its adaptability to the current house wiring system except on circuit breakers and has better integration with renewable energy sources. Analysis showed that less number of converters which gives higher efficiency and less components on the devices and also absence of reactive power eliminates power factors issues and its related harmonics.

#### f) 325V DC voltage:

The 325V DC level is the peak value of 230V AC as a Eq. 1, 230V AC appliances insulation can withstand up to 325V DC without any rupture.

$$V_{dc} = \sqrt{2} \times V_{ac} \quad (1)$$

where  $V_{dc}$  is the dc voltage and  $V_{ac}$  is the AC voltage. Sannino et al. (2003) have performed analysis on various DC voltage levels [33]: 48V, 120V, 230V, 326V and 230V AC based on the operation and installation cost in their own research facility using actual parameters and conditions [35]. The conclusions were (i) 326V DC is the best chosen voltage due to the reduced number of converters and higher efficiency. (ii) By adding back-up system (battery), can further increase the reliability in critical condition. (iii) the conventional AC circuit breakers could be used in DC low voltage distribution, provided that the ratings should be calibrated by the correction factors according to manufacturer's specification.

Hammerstorm (2007) has made the comparison between 230V AC system and 325V DC system based on the conversion efficiency of various parameters such as co-operation of RES, interruptible supplies, voltage stability, CFL lighting, variable-speed drive, power quality and concluded that without inclusion of fuel cell in DC system, its conversion efficiency is lower than AC system [36].

Waeckerle (2011) has carried out research in cables and voltage in residential buildings and reported the energy saving of 2% to 5% in 325V DC and also have made efficiency comparison between a 300V DC system and 220V AC system under the load conditions as per Mok-Dong IDC of Korea Telecom Co. Ltd. (KT) [37-38]. The result showed that the total efficiency of the 300V DC system is approximately 15% better than 220V AC system.

### g) 380V/400V DC voltaged

The 380V DC voltage level has also been using in data center by EA for a long time back and standardized for DC system. Borioli et al. (2004) have compared the proposed a split  $\pm 400V$  DC system with existing 400V AC network based on losses and transmissible power [39]. From analysis result, they have found that the transmissible power of DC system is 1.28 times more than AC system at the same current and voltage level, and power factor equal to 0.9. The power appliances in DC network are connected pole-to-pole, that is 800V DC and smaller power loads are supplied at 400V DC but with a condition, it should be balanced on both positive and negative side.

Allee and Tschudi (2012) have highlighted the standard voltage of 380V DC adopting in various data center organization. 380V DC was found to be better system than 208V-250V AC in many parameters [40]. The safety margin of 380V DC can be increased by splitting into  $\pm 190V$  DC as in IEC safety standards. The author have also debunked the existing common myths toward the 380V DC supply and presented the possibility of 380VDC standardization in future by standards bodies like EA organization.

Lucia et al. (2013) have redesigned the conventional induction cooktop with bi-directional AC-DC converter as a conjuncture device at 380V DC [41]. The considerations of 380V DC were based on Power Factor Correction (PFC) circuit voltage level, lower current for power appliances and common voltage among the engineering communities. The simulation has been carried out on various models of resonant circuits and found that the efficiency increases with the optimized resonant tank due to operating near the resonant frequency.

Shwehdi et al. (2014) have introduced a DC home as a new concept for Nano-Grid distribution system to operate as a standalone system for self-sustaining Null Net Energy (NNE) house in case of grid failure [42]. They have considered 380V DC for power household appliances and 24V for smaller rating appliances and lighting by stepping-down from 380V DC. The choice of 380V is made based on easy to integrate with the solar PV and energy storage system. Moreover, in the data center the voltage level used is 380V as a standard voltage, by splitting voltage to  $\pm 190V$  for ensuring safety and suggested that similar system could be also adopted in residences [6].

Baek et al. (2015), have proposed a DC system for integrating the utility grid, DC loads and renewable energy source and 380V DC as the chosen voltage for better efficiency and system cost [43].

### h) Other DC voltage levels

The various voltage levels have also been studied other than the above voltage levels or in Hybrid mode or in combination of three or more voltages level for different loading condition to increase its efficiencies and performance of the system. Engelen et al. (2006) have proposed three topologies of DC system to interface with the utility grid and 600VDC is chosen as suitable voltage level for Power Factor Correction (PFC) rectifier in boost topology to connect to three phase utility [44]. The different DC voltage levels are considered based on requirement: (i) 325V DC for minimum modification of existing system, (ii) 230V DC for moderate modification, (iii) 20V DC for low power appliances to eliminate the requirement of individual converters. The analysis of the power electronic conversion and conduction losses are modeled and found out that not much deviate from the AC system.

Salomonsson and Ambra Sannino (2007) have done review on various researches carried out on Low Voltage DC Distribution System (LVDC) and also experimented on AC/DC interface system to study the steady state and transient operation of the appliances [45]. The steady state analysis of the appliances load in AC and DC found that the load current in DC were more constant and also PFC circuit could be eliminated.

Starke et al. (2008) have proposed a DC distribution system and made comparison with 230V AC system in terms of efficiency [3]. The voltage level of 13.8kV, 18kV, 24kV and 30kV of both AC and DC were considered for analysis. In these studies the converter efficiency was considered as the main factor for comparison in which DC system does not harness much efficiency unless DC loads are sourced from DC source and converters are not in under loading.

Ahn et al. (2011) have modeled a power system which has divided into three sections as (i). Receptacle and plug connector (ii). EMI filter, rectifiers and PFC. (iii). DC-to-DC converters [46]. The voltage range of 240V-311V DC has the highest stability margin. They have also simplified the international safety standards into three basic methods for investigation and found out that DC system is safer than AC system at the same rating.

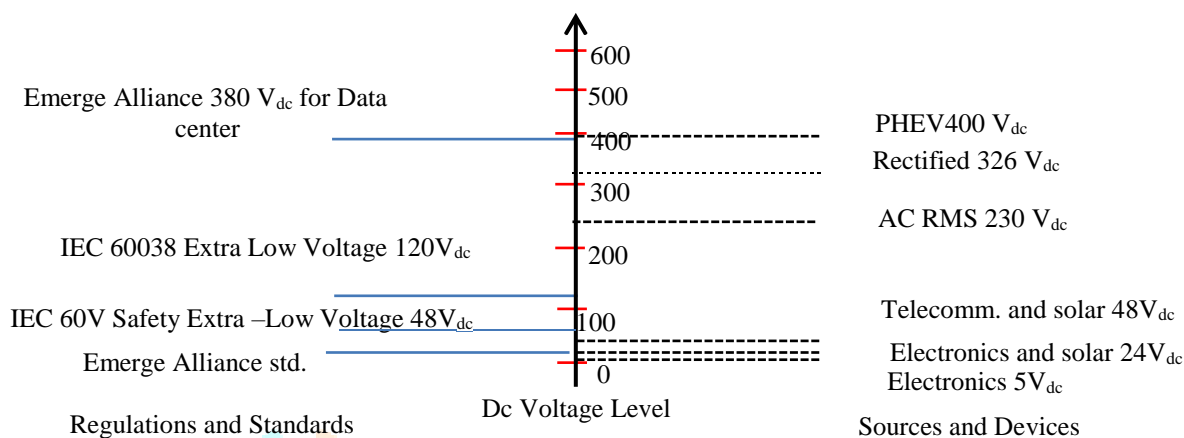
H.E. Gelani and F. Dastgeer (2015), have investigated the feasibility of the DC distribution system in residential home and presented that the efficiency of the converters changes with variation of load which result impossible to fixed at one point for evaluation [48]. Therefore, they have evaluated the efficiency variation by taking account of daily load curves and also split the various loads into different categories based on the energy demand types. The model is simulated in MATLAB /Simulink and verified that the maximum losses occurred in the DC/DC converter transformer and improving on it will impact the DC system efficiency.

Rasmussen (2007) observed that standardization of DC system is required for efficient saving in energy [55]. In IEC-60038, IEC standard voltages give the nominal voltage values for electrical system as shown in Table -1 and used as a reference for designing DC appliances [60].

**Table 1: IEC 60038 – IEC Standard Voltage.**

IEC Voltage Range	ACDS	DCDS	Electrical Risk
High voltage	$> 1000 V_{rms}$	$> 1500 V$	Electrical arcing
Low voltage	$50 - 1000 V_{rms}$	$120 - 1500 V$	Electrical shock
Extra-low voltage	$< 50 V_{rms}$	$< 120 V$	Low risk

The voltage levels above 1500 V is considered as upper limit in DC system and below 120V DC is defined as the safe zone as per IEC standards. Fig.1 gives the summary of most used voltage levels at or below 400V DC as found in the literatures [55]. The different organizations have initiated to standardize the DC voltage level based on the existing regulations, sources and devices. The two major organizations like Emerge Alliance (EA) and IEC has considered 380V DC as bus voltage level for data center where high load demands exist. EA has considered 24V DC as the Extra-Low voltage for lighting loads and low power appliances.



**Fig 1: Voltage Level for Source, Devices and Standards**

LVDC system still required to face important barriers and challenges such as lack of standards and code, safety and protection scheme, lack of industry and products, before been implemented in residential home. Many other organizations such as European Telecommunication standards Institute (ETSI), IEEE, Elegant Power Application Research Center (EPARC), Philips Research Center (PRC) and others are also actively developing the necessary standards and regulations in DC system [49].

### III. VOLTAGE LEVEL COMPARISON

The standard voltage level for DC is an important parameter affecting performance and safety of the system. Recently various studies were carried out by considering different parameters like line losses, switching surge, performance of converters but the standard voltage for DC appliances is still not well defined. The two major factors affecting the selection of DC voltage level based on home appliances are the complexity of switching at high voltage and more losses along the length of the wire at low voltage. Table.2, shows the advantages and disadvantages of various voltage levels and its suitability based on the review papers[15]-[55].

**Table 2: Suitable Voltage Level for Home Appliances.**

Volt. level	Application	Advantages	Disadvantages	Suitability level
380V/ 400V	<ul style="list-style-type: none"> <li>Data-centers</li> <li>Home appliances</li> </ul>	<ul style="list-style-type: none"> <li>Appliances PFC circuit voltage</li> <li>Can split into <math>\pm 190</math> (bipolar)</li> <li>IEC std. for power appliances</li> </ul>	More complexity of switches and circuit breakers	Moderate
325V	<ul style="list-style-type: none"> <li>BLDC</li> </ul>	<ul style="list-style-type: none"> <li>Minimum modification</li> <li>Peak value of 230V rms</li> </ul>	Complexity of switches and circuit breakers	Moderate
220V	<ul style="list-style-type: none"> <li>Home appliances</li> </ul>	<ul style="list-style-type: none"> <li>Moderate modification</li> <li>Use current wiring system</li> <li>With no performance compromised</li> </ul>	Switches and outlet need to be designed	Moderate
120V	<ul style="list-style-type: none"> <li>Home appliances</li> </ul>	<ul style="list-style-type: none"> <li>Less losses on loading distances</li> <li>USB3.1 upto 100W</li> </ul>	Optimum voltage for line losses	High
48V	<ul style="list-style-type: none"> <li>Telecom</li> <li>BLDC</li> </ul>	<ul style="list-style-type: none"> <li>Losses on feeder decrease</li> <li>Easy solar integration</li> </ul>	Cable need to be optimized, Line losses.	High
24V	<ul style="list-style-type: none"> <li>Lightings</li> </ul>	<ul style="list-style-type: none"> <li>No individual converter</li> <li>Emerge Alliance std. for low power appliances</li> </ul>	Line losses	Moderate
12V	<ul style="list-style-type: none"> <li>Lightings</li> </ul>	<ul style="list-style-type: none"> <li>Easy isolation</li> <li>Soft switching.</li> </ul>	High Line losses	Low

The voltage levels of 24V, 48V and 120V DC are considered as more suitable for household appliances. 24V DC, which has high line losses but considered as suitable due to the availability of home appliances in the market. 220V DC may be considered for power appliances because at this voltage level the minimum modification is required for adapting the existing AC system but due to high switching surge, the ratings of the switches and fuses are required to be calibrated according to the existing system.

#### IV. MODIFICATION OF HOME APPLIANCES FOR DC HOME

In transition from AC to DC system, adaptability of conventional home appliances plays a major role to reduce the overall cost. Most of the AC appliances can work safely in DC environment with or without minor modification. An AC machines which has induction need to replace with DC motors or BLDC motors to work in DC environment. The alternating machine with Variable Frequency Drive (VFD) for speed control is internally converted from AC to DC which can be used in DC with minor modification.

Rodriguez et al. have modelled various conventional home appliances such as resistive loads, appliances with motor (like Clothes Washer, Clothes Dryer, Air Conditioner, Freezer & Fridge, Ceiling Fan) and electronics loads (like TV's, Laptop, Microwave Oven) to adapt to 48V DC supply and proven that their power consumption decreases with DC supply [6].

Techakittiroj et al. (2009) have demonstrated the compatibility of conventional AC appliances such as CFL, LED and television with the DC supply without modification and simulation on steady-state shows power quality improved in DC system [50]. Paajanen et al. (2009) have suggested that ordinary incandescent lamps can used upto 230V DC and beyond which it shorten their lifetime [51]. Fluorescent tube which contained electronic as ballast can directly connect to DC input voltage up to 300V DC and heater with pure resistive elements would be economical at 750V DC.

Ahn et al. (2007) have done comparative analysis of appliances power supply circuit in AC and DC system [46]. The removal of PFC circuit in DC system makes DC appliances very simple and reduces the weight of the converters. Moreover, removal of high voltage electrolytic capacitor which is used for smoothing PFC output prolongs the appliances lifetime [52].

Various DC appliances have been developed such as a combine refrigerator-stove system to be energy efficient to run at 48V DC [5], redesigned induction cooktop home appliance at 380V DC [41], mixer grinder, LCD, Television, SMPS and LED at 220V DC [9] and Air conditioner [53]. From various surveys, many conventional appliances can work directly on DC supply with or without minor modification as listed in Table -3.

**Table 3: Home Appliances Modification**

Ref/Year	Voltage	Appliances Modified	Description
[6] 2008	48V DC	<ul style="list-style-type: none"> <li>• Resistive loads,</li> <li>• Clothes washer,</li> <li>• Freezer and fridge</li> <li>• Ceiling fan</li> <li>• TV</li> <li>• Laptop</li> <li>• Microwave oven</li> </ul>	<ul style="list-style-type: none"> <li>• Modification of power supply of appliances.</li> <li>• Performed analysis of power consumption reduction a month.</li> <li>• Performed analysis of the reduction of renewable energy source requirement.</li> </ul>
[50] 2009	Not mentioned	<ul style="list-style-type: none"> <li>• CFL</li> <li>• LED</li> <li>• Television</li> </ul>	<ul style="list-style-type: none"> <li>• Performed experiment on appliances without modification</li> <li>• Measurement of current, voltage and power are carried out.</li> </ul>
[51] 2009	220V 400V 500V	<ul style="list-style-type: none"> <li>• Incandescent bulb</li> <li>• Fluorescent tube</li> <li>• Heater</li> <li>• Universal and DC motor.</li> </ul>	<ul style="list-style-type: none"> <li>• Suggested that these appliances can work directly on AC or DC supply without modification.</li> </ul>
[46] 2011	380V	<ul style="list-style-type: none"> <li>• AC power converting circuit</li> </ul>	<ul style="list-style-type: none"> <li>• Convert AC power supply into DC supply by eliminating the components</li> <li>• Analysis of existing international safety standard.</li> <li>• Performed on switching analysis at high voltage.</li> </ul>
[5] 2011	48V	<ul style="list-style-type: none"> <li>• Refrigerator- stove</li> </ul>	<ul style="list-style-type: none"> <li>• The system prototype has been developed and simulated on MATLAB.</li> <li>• Performance is analyzed.</li> </ul>
[41] 2013	380V	<ul style="list-style-type: none"> <li>• Induction cooker</li> </ul>	<ul style="list-style-type: none"> <li>• Designed the system, simulation and experimental tests were performed.</li> </ul>
[9] 2014	220V	<ul style="list-style-type: none"> <li>• Mixer grinder</li> <li>• Induction cooker</li> <li>• LCD Television</li> <li>• SMPS</li> <li>• LED</li> </ul>	<ul style="list-style-type: none"> <li>• Modified power supply of conventional appliances and made performance comparison with AC system.</li> <li>• Explained the possibility of using SMPS and LED for DC source.</li> </ul>

[3] 2016	48V 300V	<ul style="list-style-type: none"> <li>Refrigerator motor</li> <li>Ceiling fan</li> <li>AC compressor</li> <li>Washing machine</li> <li>Water purifier</li> <li>Mixer grinder</li> </ul>	<ul style="list-style-type: none"> <li>Replaced motor of home appliances with BLDC motor.</li> <li>Performance comparison has done between the existing appliances and their counterpart with BLDC motor.</li> </ul>
[53] 2017	240V	<ul style="list-style-type: none"> <li>Air conditioner</li> </ul>	<ul style="list-style-type: none"> <li>Experimented hybrid power supply for air conditioning equipment.</li> </ul>

## V. PROTECTION IN DC SYSTEM

DC unlike AC does not come to zeros in every cycle which brings the difficulties of breaking the DC current and grounding [45]. Various authors have presented switching solutions for DC. Baek (2015) presented a special design for plug and connector using solid state switch with relay for safe interrupting the DC high current and better option for replacing the mechanical switch as shown in Fig. 2 [43].

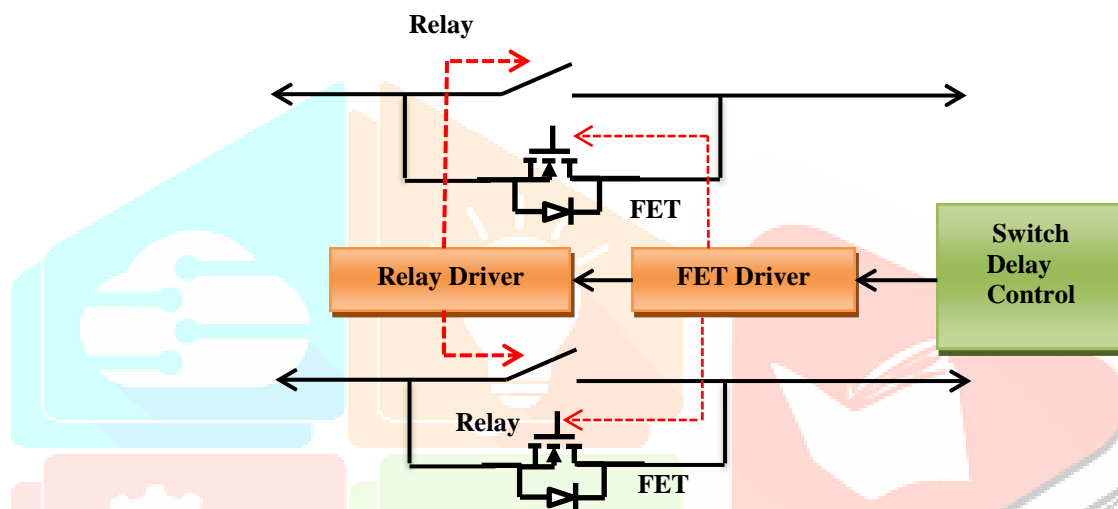


Fig.2: DC Switch Connector

Few suggested several possibilities are (i) creating larger distance between the contacts in the circuit breaker [45] (ii) using three phase circuit breaker which has three contact pairs in series [56] (iii) a magnetic field to stretch the arc and also a breaker with a resonant circuit [57] which brings zero voltage. These solutions may be feasible in DC but external source is required to trip the devices and cost higher.

Ahn et al. designed a test bed of 5kW DC power supply with resistive loads to perform an experiment at 380V DC on plug-in/plug-out operation and found that electrical fire or shock were not ever occurred except some instant spark and draw a conclusion that it could be a gradual risk, but not instant risk [46]. Similarly, Jeon et al. (2011) have also performed a testing at 380V DC and solved the problem by adding a capacitor/a shunt diode branch to the plug [47].

Meyer and Rufer have developed a hybrid circuit breaker with ultra-fast contact opening and Integrated Gate-Commutated Thyristor Switch (IGCT) and experimented on 4kA, 1.55kV system and results showed a huge decreased in the current interruption time [58].

Mehl and Meckler (2013) held a comparison between mechanical and electronics breaker at 400V DC system and found electronics breakers are better than mechanical breaker in many parameters but suffer from leakage current in off-state, do not provide complete isolation and induces voltage spike during operation [59]. From above survey, a standard low cost switch and fuse are needed to developed for implementing in DC Home.

## VI. DC VOLTAGE LEVEL FOR RESIDENTIAL IN RURAL INDIA

There are various benefits and barriers for standardizing DC system [8] and also many efforts have been done in research level but due to the lack of (i) standards and codes (ii) safety and protection issues (iii) industry and products [8],[49]. The cost of implementation of DC home is still high in present situation. Considering a typical rural Indian household where load rating is not much as in data center and taking 380V as bus voltage for distribution system would not be economical and also it increases the complexity of the system. Therefore, for rural area, lower voltage level need to consider adapting lower power demand.

Chauhan et al. presented the various available DC appliances in India with voltage level varying from 12V DC to 96 V DC depending on the type of loads [8]. At 24V DC, lighting load rating can go up to 110W [19]. Considering all the different arguments 24V DC may be the suitable choice for lighting loads due to the following reasons:

- (i) Commercially, household appliances are available at voltage level of 12V, 24V and 48V DC [55].
- (ii) The DC voltage level below 50V is safe for even direct contact [21].
- (iii) The line losses and voltage drop across the cable are less than 12V DC level and safer as compared to 48V DC.
- (iv) Using a simple buck and boost converter, the voltage can be step-down to 12V and step-up to 48V DC if necessary.
- (v) Conventional 230VAC switches, fuse, socket and existing wiring can be used directly without modification.
- (vi) This level is frequently used as PV and battery voltage level.

The voltage level of 48V DC may be also considered as the bus voltage due to the following reasons

- (i) It can power up to several hundred watts which would cover all electronics, IT and entertainment equipment.
- (ii) It has been using in telecom industries for long time.
- (iii) DC appliances are also available at this voltage level.
- (iv) It is lower voltage rating for BLDC motor.
- (v) It does not require protection against indirect contact.

For power appliances, 120V DC can be chosen as power line voltage for rural Indian household due to the following reasons

- (i) In [60], IEC defined this level as upper boundary of Extra –voltage and safe under dry condition.
- (ii) The line losses and voltage drop is much dominant on cable above this level.
- (iii) It can handle power rating up to 3000W.
- (iv) Conventional circuit breaker can be used as a switch for operating the appliances without modification.

## VII. CONCLUSION

This study investigated the voltage levels and modification of home appliances to adapt in DC home in recent researches level. Unlike AC systems, a well-established set of standards for household DC networks is currently lacking. However, several recommended standards and configurations have been discussed. This work reviews some of the most suitable voltage levels of DC distribution to be implemented for a rural Indian home. The DC voltage of 24V and 120V are chosen as probable voltage levels for lighting loads and power loads respectively based on its adaptability to current AC system and availability of international standards. The other higher DC voltage like 380V may be considered in coming days after standardizing appliances, equipments, sources and safety measures for DC system. Moreover, there are several other benefits of using the concept of DC home where main electricity grid cannot reach in rural or remote areas, and also less numbers of converters is required while tapping energy from renewable energy sources and more safe at lower voltage levels.

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