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Research Article

Efficiency Comparison of Alternating Current (AC) and Direct Current (DC) Distribution System at Residential Level with Load Characterization and Daily Load Variation

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Abstract: The war of currents between alternating current (AC) and direct current (DC) is decades old. The DC has proved itself in the fields of generation and transmission; now it is making its way at distribution level in quite an efficient fashion. The DC seems to be challenging the AC, as a result of efficient DC to DC as well as to and from AC conversion with the development of efficient power electronic converters. This paper presents efficiency comparison of the two paradigms for a residential colony. The model is separately simulated for AC and DC supply from the grid keeping the infrastructure for both schemes unchanged. The residential loads are divided in to three categories depending upon their supply requirements. The loads are further classified according to their time of usage during the whole day. The efficiency comparison between AC and DC system is established on the basis of daily load variation.

Keywords: AC, DC, efficiency, residential, load categories, load variation

1. INTRODUCTION

The so called war of currents between alternating current (AC) and direct current (DC) has its roots from the very start of electricity. The pioneers of electricity generation Edison and Tesla both had their own views of mode of electricity. Edison supported DC as mode of electricity whereas Tesla supported AC. In the beginning AC winning the battle of currents due to invention of transformers, an easy and cost effective way of stepping up and stepping down voltages as required.

Alternating current was considered the champion in all sections of electricity, i.e., generation, transmission and distribution. However AC enjoyed dominance and superiority over DC for not a long period of time. Researchers were constantly putting efforts to find new modes of generation and that lead to the invention of renewable resources like solar panels and fuel cells that produced power in the form of DC. Direct current has proved itself in transmission area better than AC due to lesser losses. With the advancement of research in the relative field DC made its way in the distribution section. Direct current challenging AC at distribution level due to the invention of highly efficient power electronic converters and several DC operated electronic loads.

At residential level DC has entered our bedrooms, kitchen and garage. Many of residential

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loads are DC operated; our microwave ovens, computers, laptops, phones, lighting and electric vehicles. The feasibility of DC distribution and its comparison with AC has been the interest of many researchers since years. The comparison is made on the basis of efficiency, cost and losses [1]. Conversion loss comparison was made by Seo et al. [2]; they suggested that with local generation DC is better than AC as far as conversion losses are concerned. It was further proved that converter efficiency is directly proportional to loading. In case of DC distribution, DC-DC converter is the heart of the system and its losses were studied by Gelani and Dastgeer [3]. The authors proposed that the conversion losses of the main DC-DC converter have serious impact on the overall efficiency of DC distribution system of a residential colony.

Starke et al. [4] created two models and simulated them with AC and DC separately. It was proved that for the same conduction losses DC is 1.22 times better than AC. DC proved to be a better choice within buildings considering losses, safety and power quality [5]. The authors also presented a model with different operating voltages for DC distribution system and it was suggested that a voltage level of 326V is best suited keeping in view the power loss and voltage drop. Another topology presented by Nilsson and Sannino et al. [6] considered three designs; DC, AC and mixed AC/DC. The mixed system was proved to be worst as regards to system losses and DC system was proved to be better than AC only when semiconductor losses are considered half. With DC as medium of power transfer; several research efforts are made involving distributed generation and microgrids for colonies. The losses involved in power transfer comprising conversion losses have been an interest to many researchers [7-10]. The authors presented different models at microgrid level, compared AC with DC and deduced their results favoring DC over AC. Besides DC gaining success over AC in many areas yet DC lags AC in many fields, the major one being protection. As there is no null point in DC, employing DC at distribution level is a threat. As well as the deciding feature in the efficiency calculation is the DC-DC converter whose efficiency varies with the load therefore at low loads the efficiency of DC system will be lower than that of AC system [3].

This paper presents a model of a residential colony comprising 50 homes. The model is separately simulated for AC and DC supply from the grid. The infrastructure of the colony is kept the same for both simulations. By infrastructure; the conductor type, resistance and load demand is meant. The loads are divided in to three categories depending upon their supply demand. A further classification of the loads is made on the basis of their time of usage. Six periods, each period of four hours is developed and the system is simulated for each period with AC and DC supply.

2. LOAD CLASSIFICATION

The common residential loads are divided in following categories:

DC Loads: The loads that require DC power for their operation.

AC Loads: The loads that require AC power for their operation.

AC/DC Loads: The loads that can be run both on AC and DC for their operation. These loads include majorly heating loads. When the system is simulated with DC supply, the supply to these loads will be DC and for system's AC supply, these loads will be run on AC.

Table 1 shows classification of residential loads according to their time of usage. A full day is divided into six periods, each period of four hours. Obviously loads do not operate for twenty four hours; the loads are divided in sections of their time of usage. Table 2 presents classification of AC, DC and AC/DC loads according to their time of usage. An average home consumes 30kWh

Table 1. Period load classification in kW.

Appliances	Period-1 (0:00-4:00)	Period-2 (4:00-8:00)	Period-3 (8:00-12:00)	Period-4 (12:00-16:00)	Period-5 (16:00-20:00)	Period-6 (20:00-0:00)	Total
Air Conditioning	1.5	1.5	0.2	0.2	0.5	1.2	5.1
Space heating	0.8	0.5	0.4	0.3	0.6	0.7	3.3
HVAC Appliances	0.2	0.27	0.25	0.23	0.25	0.3	1.5
Cooking	0.5	2.2	1.2	2	1.5	1.3	8.7
Water Heating	0.2	0.8	0.4	0.5	0.7	0.4	3
Lighting	0.1	0.2	0.2	0.6	1.1	0.8	3
Electronics	0.1	0.2	0.6	0.5	0.6	0.4	2.4
Laundry Appliances	0.1	0.4	0.6	0.3	0.5	0.2	2.1
Others	0.05	0.06	0.3	0.19	0.2	0.1	0.9

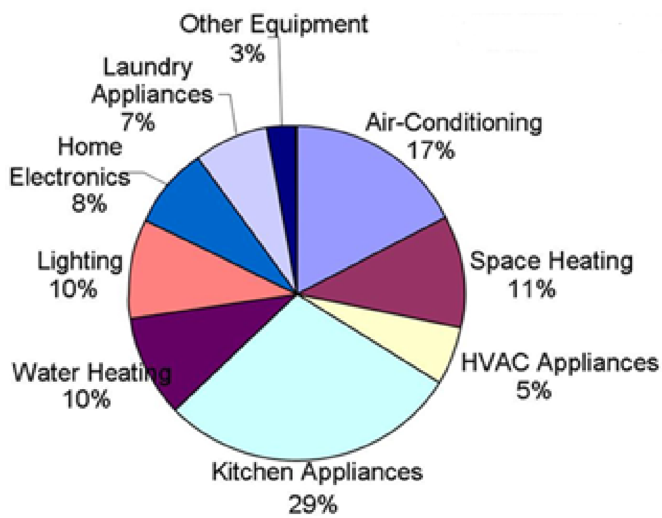

Fig. 1. Residential electricity consumption.

per day [3]; hence the loads are allotted power according to the percentage of 30 kWh. From the pie chart of Fig. 1 [11], the percentage share of each residential load helps in calculating wattage of each load consumed throughout the day e-g share of air-conditioning unit is 17% and 17% of 30kW is 5.1KW. This 5.1kW is distributed according to the time when air conditioning unit is operational.

3. MODELING AND SIMULATION

As stated earlier that a residential colony of fifty (50) homes is modeled. DC power from the grid reaches DC-DC converter which steps down the grid voltage to 325V. The reason of delivering 325V at homes is to fully utilize the conductors. The peak value of generally employed 230V RMS is approximately 325V.

The effect of efficiency variation of DC-DC converter with loading is shown in Fig. 2 [12]. Each main DC-DC converter supplies ten homes as shown in Fig. 3. The homes are equipped with AC, DC and AC/DC loads. Each home has its own DC-DC converter to further step down the voltage suitable for DC loads and an inverter for AC loads as shown in Fig. 4.

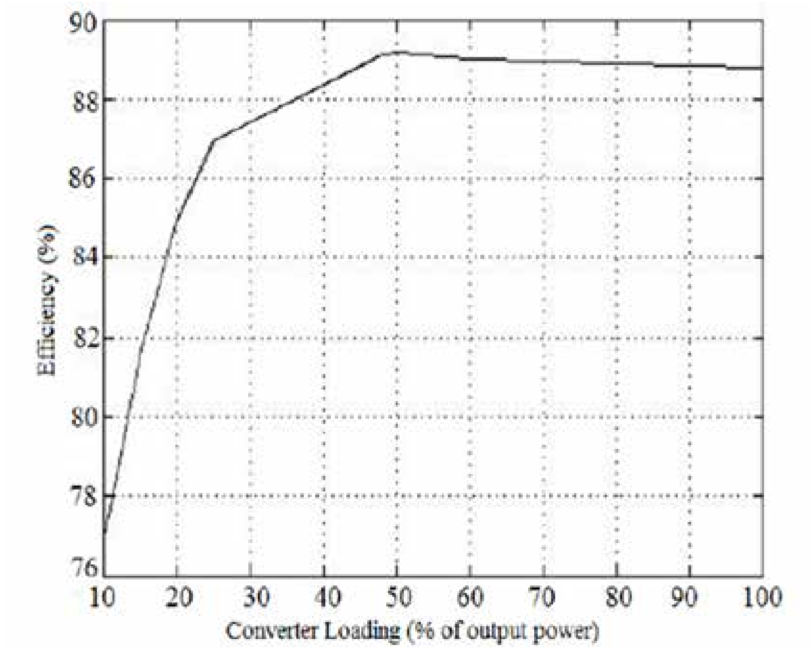

Fig. 2. Efficiency vs loading for DC-DC converter.

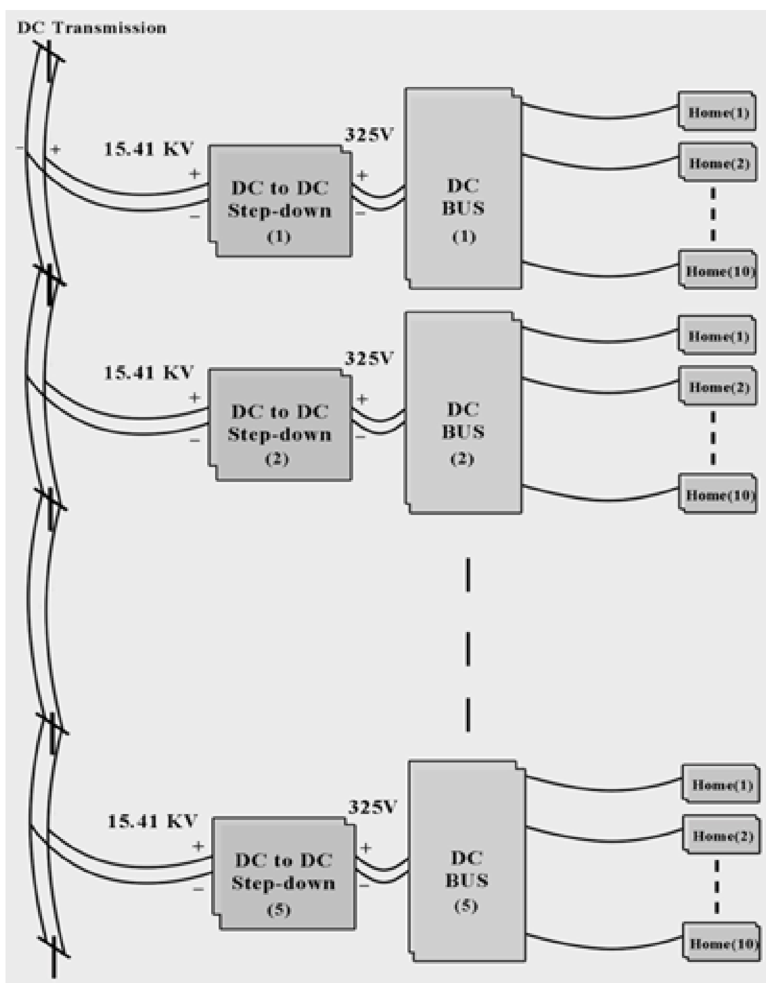

Fig. 3. Residential colony for DC grid.

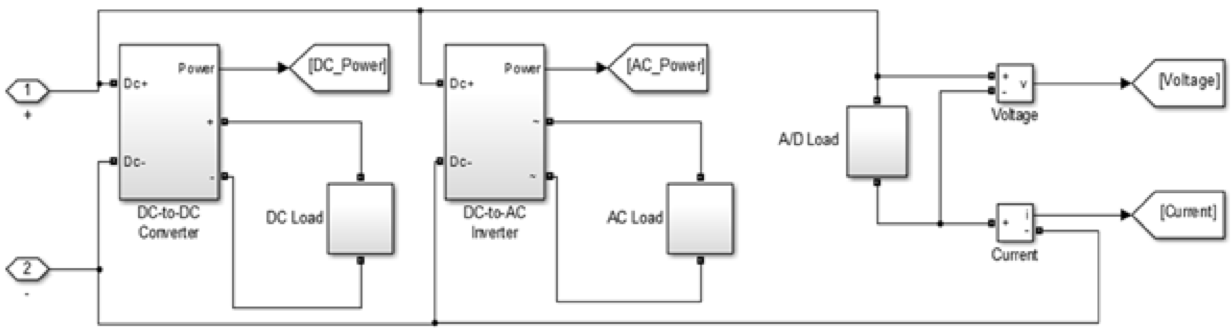

Fig. 4. Inside home circuitry for DC colony.

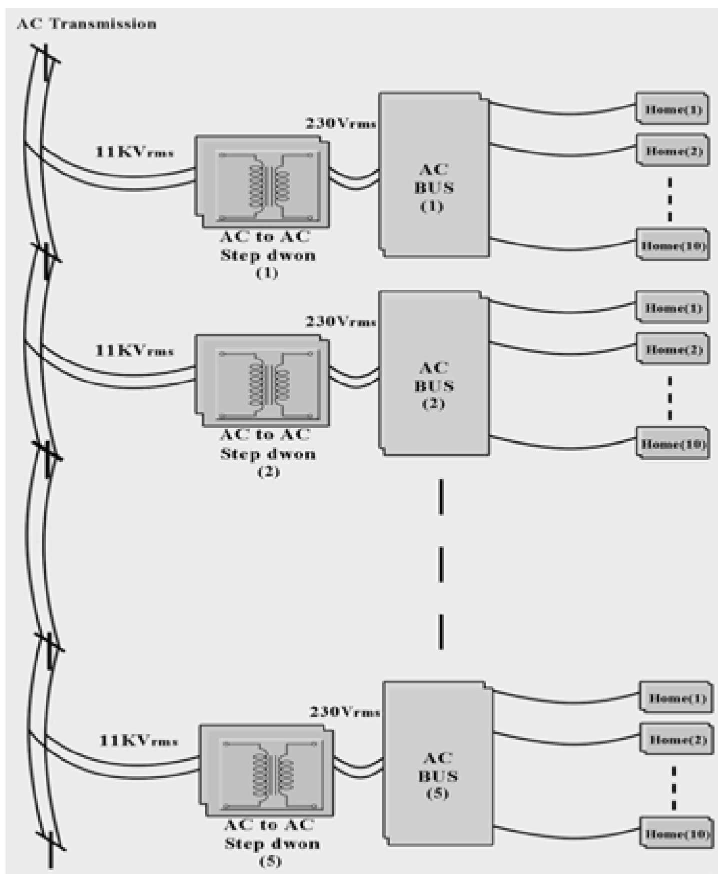

Fig. 5. Residential colony for AC grid.

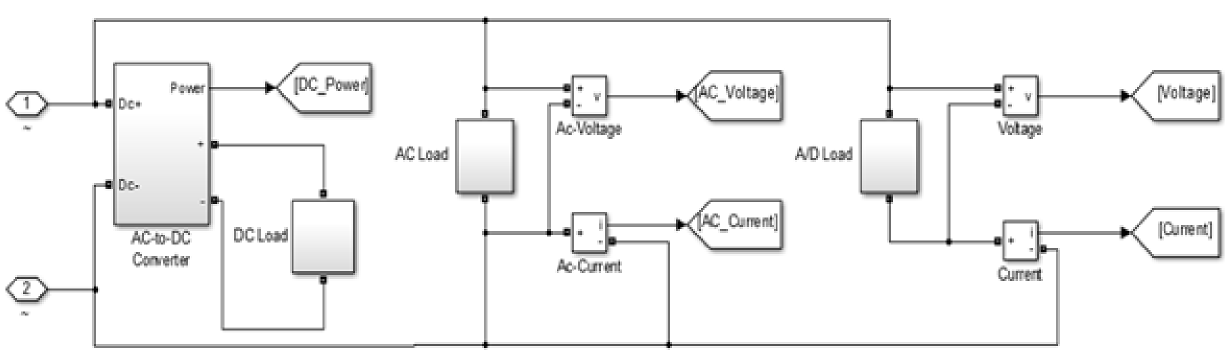

Fig. 6. Inside home circuitry for AC colony.

The same model of fifty homes is simulated for AC grid with suitable changes in fig. 3 as shown in Fig. 5. The main DC-DC converter is replaced by transformer; as DC-DC converter in the previous case. Due to the fact that transformer's efficiency variation with loading is very low therefore transformer is also assumed to operate at its maximum operating efficiency. Fig. 6 depicts each home is now equipped with a rectifier for DC loads and no need of another transformer because AC loads can run on 230V from the main transformer.

In order to make the simulation as near to practical as possible; conductor and converter (DC-DC, transformer and inverter) losses are given their due portion. The losses are characterized in to three categories: constant, linear and quadratic according to their relationship with the output power. Of these linear losses making up major portion the lot, comprise of switching loss [3].The switching losses occurring with their proportion are shown in table 3 as included in the simulation. Inductor and Capacitor power loss is modeled by placing series resistance with ideal inductor and capacitor respectively. On state switch loss is modeled by taking product of switch voltage and current in on state; transient switch loss is modeled by measuring power loss in fall time and tail time of the switch. Diode power loss is calculated by multiplying on state voltage and current whereas gate driver loss is adjusted by pulse count and time for pulses for a fixed period. Both models are simulated for six periods of time and results are tabulated. The efficiency for each period is found by using the simple relation P_{out}/P_{in} . Standard *Drake* [13] ACSR (Aluminum Conductor Steel Reinforced) is employed with 0.025Ω/mile dc resistance and

Table 2. Period wise supply load classification in kW.

Categories	Period-1 (0:00-4:00)	Period-2 (4:00-8:00)	Period-3 (8:00-12:00)	Period-4 (12:00-16:00)	Period-5 (16:00-20:00)	Period-6 (20:00-0:00)	Total
AC	1.8005	2.1706	1.053	0.7319	1.252	1.701	8.709
DC	0.2005	0.4006	0.803	1.1019	1.702	1.201	5.409
AC/DC	1.5005	3.5006	2.003	2.8019	2.802	2.401	15.009

Table 3. Converter loss contribution.

Loss Type	Proportion per Converter
Inductor Power Loss	0.5%
Capacitor Power Loss	0.7%
Switch Loss- On state	0.15%
Switch Loss- Transient state	1.8%
Diode Power Loss	0.8%
Gate Driver Loss	0.25%

Table 4. Period wise efficiency of AC and DC colony

Efficiency	Period-1 (0:00-4:00)	Period-2 (4:00-8:00)	Period-3 (8:00-12:00)	Period-4 (12:00-16:00)	Period-5 (16:00-20:00)	Period-6 (20:00-0:00)
AC	91.36%	92.63%	88.91%	83.99%	90.11%	91.09%
DC	77.65%	82.33%	85.23%	91.21%	95.41%	92.31%

0.1172Ω/mile ac resistance. The pole spacing in system is kept at 30 meters and ac/dc resistance values are adjusted accordingly.

4. RESULTS AND DISCUSSION

The results tabulated in Table 4 present the efficiency values throughout the day. Different loads operate at different periods of time. For periods 1, 2 and 3; the efficiency of AC grid is higher than that of DC grid. The reason is dominance of AC loads during these periods. The difference between AC and DC grid efficiency for periods 1 and 2 is large due to the fact that DC loading is quite low in these periods and considering the curve of Fig. 2 the DC-DC converter efficiency is very poor at light loads. The loss coefficients evaluated in [3] for DC-DC converter revealed the maximum dependency of DC distribution system on main DC-DC converter therefore with poor efficiency values for DC-DC converter at light loads has a direct impact on system's efficiency.

As DC loads increase operating during day time, the efficiency of DC-DC converter increases and in turn the efficiency of DC grid enhances. DC dominates AC in periods 3, 4 and 5 but the difference between AC and DC grid efficiency values are not to an extent as it was for periods 1, 2 and 3. With DC loads increasing in our society this difference will however be overcome and there is a chance that DC dominates AC throughout the day.

Despite the fact that power electronics has gained so much success that highly efficient are available [3]; a conversion stage still holds responsible for efficiency evaluation of a system. Another reason for excellent efficiency of AC grid as compared DC grid as well as better average efficiency of AC grid is the fact that AC grid lags a conversion stage inside home than DC grid. The inside home circuitry of DC grid has two converters as compared to AC grid having only one.

5. CONCLUSIONS

In the light of above discussion, it is concluded that in order to improve the efficiency of DC grid, the efficiency of DC-DC converter needs to be improved particularly at light loads because this is one of the major reasons that DC lags AC in efficiency in three out of six periods presented in this research effort. The DC-DC converter is the "backbone" of the system therefore; its efficiency decides the efficiency of the system. Finding appropriate solution to the problem highlighted in this research effort may lead to a new world of DC distribution research. As specified, DC is entering the area of power distribution after proving itself in power transmission and there is a chance that DC regains its fame that it had at the origin of electricity era.

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