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POWER SYSTEMS AND POWER ELECTRONICS

Comparative analyses of residential building efficiency for AC and DC distribution networks

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Abstract. The escalating prevalence of rooftop solar PVs and DC powered home appliances are the driving forces for the research in the field of DC distribution at residential level. The current research work presents comparative analyses of AC and DC distribution systems considering various scenarios for the specific purpose of efficiency/energy savings. A modern Bakersfield CA, USA home is considered for the analyses. The loads are classified according to the power demand. Rooftop solar PVs are also included in each residential building. Mathematical equations are devised for the efficiency analysis of residential buildings powered with AC as well as DC. The results reveal strong dependence of the efficiency values on the utilization/types of loads, efficiencies of the power electronic converters (PECs), solar capacity and seasonal conditions, as a function of the time of day. It is concluded that AC system presents better efficiency values as compared to the DC counterpart except during the time periods when solar power is available and when the penetration of variable speed drive (VSD) based loads is high.

Key words: DC distribution system; efficiency analysis; AC vs DC; residential buildings; solar PV.

1. Introduction

The ‘battle of currents’, between AC and DC as the medium of power transfer has its roots in the 19th century when the technologies invented by the pioneers of electricity Edison and Tesla came face to face [1]. The battle was predominantly won by AC, advocated by Tesla, due to the invention of electromagnetic transformers. DC lost the battle at first place because it had no means of voltage transformation at that time and DC system had to face ‘power transportation loss over long distances [2–4]. AC began its era in the 19*th* century and ruled over all sectors of electric power system [5]. AC enjoyed its supremacy from the age of small, isolated networks to the current highly interconnected power systems. However, this dominion of AC was not everlasting. The first setback that AC had to face was the first commercial high voltage direct current (HVDC) transmission, Gotland 1, in 1954 [6]. This was the result of optimized power transmission over long distances with DC as medium of power transfer as compared to AC.

The success of DC links to the technological development in the field of power electronics and in turn the commercial availability of highly efficient power electronic converters (PECs) [7]. The PEC breakthrough granted DC the characteristic, due to the absence of which DC lost the battle at first place, i.e., voltage transformation.

Besides power transmission sector, DC paved its way to the generation sector in the form of solar PVs [8, 9]. Energy from wind can be better optimized with DC; because wind has to go through two power transformations in case of AC as compared to one power transformation in case of DC. The new millennium has witnessed expeditious spread of solar PVs at rooftops due to their commercial availability and economic reasons. The trend of rooftop solar PVs has further added to the DC side; thereby weakening the role of AC in power system. The rooftop solar PVs and shifting trend towards the DC based loads as a result of the development of efficient PECs has resulted in the realization of the DC distribution system. A concrete foundation in this regard is furnished by the on-going trend of the utilization of variable speed drive (VSD) based loads in the residences, due to their energy-savings characteristics [10]. The case of VSD based loads is identical to that of wind in the sense of transformations; hence the VSD loads can also be better optimized with DC system as compared to AC.

DC has set a firm foot in generation and transmission. The utilization sector is welcoming DC in the form of rooftop solar PVs and the utilization of DC as well as VSD loads in residences. The distribution sector is still in its research phase. It is yet to be decided whether the residences are efficient with DC or AC supply. Efficiency or power loss was the reason which ruled DC out during the first encounter and it can be said that this could be the same variable possessing the tendency of bringing DC back to the scenario. Therefore, the efficiency analysis holds a significant position in deciding the fate of DC.

This paper presents the feasibility of DC at residential in the context of comparative efficiency analyses between AC and

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DC, considering factors that affect the performance of AC as well as DC systems. The analyses are performed under various scenarios to present a comprehensive comparison between AC and DC systems. It may be said that the aim of this research is to present a realistic comparison by keeping the system parameters/conditions as realistic as possible. In order to accomplish this, the loads and solar irradiance data of Bakersfield CA, USA has been utilized [11, 12]. The information of energy usage of a typical US residence is taken from Energy Information Administration (EIA) [13, 14]. The effect of daily load usage, PECs efficiency, solar capacity and seasonal conditions on the efficiency of AC and DC systems is highlighted as a function of time of day.

2. Literature review

The area of DC distribution has been explored by many researchers. Noteworthy research has been presented in the past that addresses the feasibility of DC distribution networks as well as the comparative efficiency analysis of AC and DC distribution systems.

The research presented in [15] highlights the loss comparison of DC distribution for two voltage levels (24 V and 48 V). In the end it is concluded that the DC system with 48 V is a better choice from the efficiency point of view as compared to 24 V. It is important to state here that the authors did not consider load variation for the study. In contrast, the current research focuses the variation of the efficiency of system by considering load variation throughout the day. The authors of [16] modeled AC and DC systems with the inclusion of solar PV. They concluded that the solar energy is better utilized in the DC system as compared to the AC system. However, a single load type i.e., LED is considered for the analysis whereas the current research takes into account realistic data from EIA with all the loads of a typical residential building.

The author of [17] concluded that only if local generation is provided, then DC is a better option as compared to AC. The author considered all loads as DC and assumed fixed conversion loss. In contrast, current research takes into account all the typical residential loads and classifies them according to the power demand. Furthermore, the variation of PECs efficiencies with the loading is also considered in the current research. The work presented in [18] is another efficiency comparison of the two paradigms. The authors assumed quite high as well as fixed values of PEC efficiencies (up to 99.5%); the authors themselves stated in the article that such high-value converters are quite rare commercially.

Similar to the work cited earlier, the authors of [19] presented their efficiency analysis with an assumption that all loads are DC; furthermore, the authors ignored the conversion stages and associated losses. The work presented in [20–29] is similar to [17] and [19] as regards to the assumption that all loads in residence are inherently DC. In contrast to the current study, the authors of [22, 23, 30–33] assume fixed efficiency of the PECs. The research efforts [10, 34, 35] are three of our own earlier studies related to the efficiency analysis of DC power distribution. In [34], the feasibility of DC as medium of power at distribution scale is highlighted. We did not present the comparative efficiency analysis of DC and AC distribution systems. The load variations were arbitrarily determined on the basis of assumptions. However, in this study we are utilizing realistic data from EIA. In [10], the efficiencies of the PECs are not taken considering the load variation i.e., the dependence of PECs efficiencies on loading is ignored; whereas the theme of the current effort is based on changing efficiencies of converters with loading. The comparative analysis presented in [36] does not consider seasonal variations as well as the VSD loads are neglected. Whereas in the current paper seasonal effect is addressed as well as VSD loads are also considered. A time-based study is missing in [37]; the authors present comparative efficiency analysis on the basis of assumptions. In addition to the comparative efficiency analyses of AC and DC distribution networks considering daily load variation based on actual data and PEC efficiencies varying with loading, the current research features the study of the effect of actual solar irradiance variations in a day. Furthermore, seasonal effect on the efficiencies of AC and DC systems is also presented in the current study. The present body of knowledge contains studies that have presented the effect of solar PVs in the DC distribution due to the shifting trend towards renewable resources; for example the work presented in [37] and [38]. However, the authors of both studies did not compare AC and DC distribution at the residential level considering hourly load as well as solar irradiance variations.

In the light of the above discussion, it is revealed that in most of the cases bias can be observed towards DC by considering all the loads as DC. The true effect of PECs is not presented by considering fixed efficiency of the PECs. Furthermore, the seasonal effect is ignored, the power from solar PVs changes throughout the year as well as the load demands of several loads change with climatic variations throughout the year. In order to cover the gap in the present body of knowledge, it is aimed to present a comprehensive study that addresses all the stated loopholes in a realistic fashion

3. System modeling

3.1. Loading Conditions for DC and AC System. Data is extracted from EIA for a typical Bakersfield CA, USA home. The loads are categorized according to power demand and the loading calculations are performed using the data from EIA. The models for DC and AC building block (BB) are presented in Fig. 1.

3.2. Classification of loads. The data presented in energy data book (EDB) of EIA are classified into four categories as A, D, I & VSD loads according to the power demand.

- A category loads: the loads which are AC in nature and require AC supply for their operation.
- D category loads: the loads which are DC in nature and require DC supply for their operation.

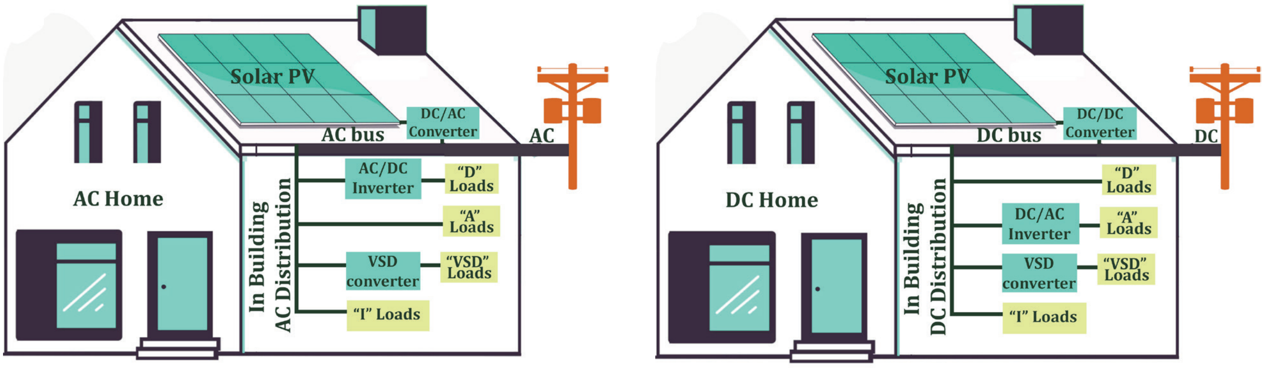

Fig. 1. Modeling of AC and DC BB

- I category loads: the loads which are independent of the input supply i.e., these can be driven on AC as well as DC supply.
- VSD category loads: the loads which are operated through variable speed drive (VSD).

3.3. Load calculation. The data from EDB are in the form of Quadrillion British Thermal units (Quad BTUs). In order to convert these values into kWh per day, load calculations are accomplished by using daily energy usage from EIA; according to which the total energy demand of a residential BB is calculated to be 30 kWh/day. This value of energy demand is divided to each type of load according to daily usage. For example, for space heating, the portion of energy consumed can be found using:

$$0.5088/4.9498 = 10.279203\%.$$

Using this percentage, the kWh/day of space cooling can be found from:

$$10.279203\% \text{ of } 30 \text{ kWh/day} = 3.08376 \text{ kWh/day}.$$

The values of energy in kWh for all other loads are calculated in the similar fashion and the result is presented in Table 1. VSD loads are considered to address modern trend of shifting of AC loads to VSD. However, the trend has not yet taken a mature shape; therefore, half of the AC loads are considered as VSD loads in the study. However, a variation in VSD loads penetration is also presented in the coming section.

3.4. Load variation. Since the theme of this study is to encompass the effect of daily load variation, the energy demands calculated in Table 1 are further divided into 24 hours. To do so, the daily load curve pattern of Bakersfield CA USA is utilized; where power demand of space heating at 1pm is 1.968% of the total day's consumption; hence:

$$1.968\% \text{ of } 3.083761 \text{ kWh/day} = 0.060686211 \text{ kW}.$$

Similar approach is followed to calculate the load demand of space heating and all the loads for 24 hours to formulate the graph for daily load consumption of a typical residential BB presented in Fig. 2.

Table 1
Energy value in kWh/day

Category	Energy used (Quad. BTU)	Energy (kWh/day)	A, D, I & VSD categorization
Space Heating	0.5088	3.083761	VSD
Space Cooling	0.5744	3.481353	A
Water Heating	0.5188	3.144854	I
Lighting	0.7588	4.599459	D
Electronics	0.6088	3.690331	D
Refrigeration	0.2594	1.572427	A
Wet Cleaning	0.1994	1.208776	A
Cooking	0.2488	1.508425	I
Computers	0.2388	1.447816	D
VSD operated Space Cooling	0.57444	3.481595	VSD
VSD operated Refrigeration	0.25944	1.572427	VSD
VSD operated Wet Cleaning	0.19944	1.208776	VSD
Total	4.9498	30	

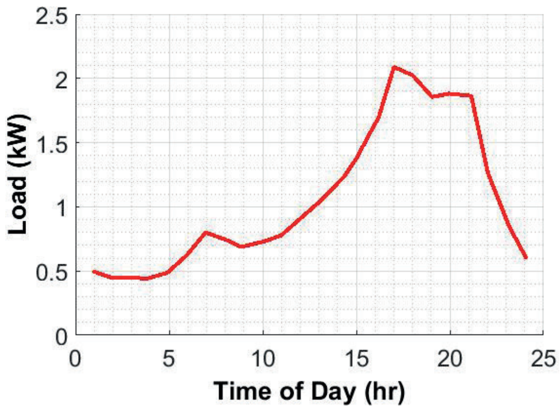

Fig. 2. Daily Load Curve for a residential BB

The MATLAB curve fitting tool is utilized to find the mathematical equation for the daily load curve shown in Fig. 1; the equation is presented in (1)

$$\begin{aligned} p_{\text{load}}(t) = {} & (2.093)\sin((0.1274)t+(0.1972)) \\ & +(1.329)\sin((0.2333)t+(2.822)) \\ & +(0.2591)\sin((0.5385)t+(-2.282)) \\ & +(0.6242)\sin((1.779)t+(1.091)) \\ & +(0.08905)\sin((1.308)t+(-1.521)) \\ & +(0.6112)\sin((1.763)t+(-1.952)), \end{aligned} \tag{1}$$

where $p_{\text{load}}(t)$ represents the instantaneous load and t is the time of day.

3.5. Modeling of solar power. The DC as well as AC residential BB is equipped with locally generated solar PVs setup at rooftop. In order to make the analysis realistic, the solar irradiance data of the same location i.e. Bakersfield CA, USA is utilized.

The MATLAB curve fitting tool is again used for determining the equation of the solar irradiance curve presented in Fig. 3; the equation is presented in (2)

$$P_{\text{solar}}(t) = (0.9609)\exp\left(-\left(\frac{t-(12.24)}{3.075}\right)^2\right), \tag{2}$$

where $P_{\text{solar}}(t)$ and t are the instantaneous solar power and the time of day respectively.

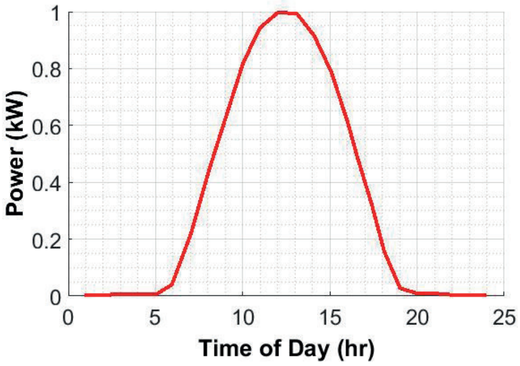

Fig. 3. Solar curve for Bakersfield CA

4. Mathematical modeling of DC BB

The D, A, I and VSD loads share fraction of overall power demand of BB, which can be represented as α, β, γ and δ percentage of the $p_{\text{load}}(t)$ respectively. Mathematically, presented in Eqs. (3) to (6)

$$p_{\text{D}}(t) = \alpha \times p_{\text{load}}(t), \tag{3}$$

$$p_{\text{A}}(t) = \beta \times p_{\text{load}}(t), \tag{4}$$

$$p_{\text{I}}(t) = \gamma \times p_{\text{load}}(t), \tag{5}$$

$$p_{\text{VSD}}(t) = \delta \times p_{\text{load}}(t), \tag{6}$$

The DC–DC converter proposed in [39] is utilized for the DC-DC conversions. The efficiency curve of the DC–DC converter can be represented in the form of a polynomial equation as shown in (7)

$$\begin{aligned} \eta_{\text{DC–DC}}(p) = {} & (-8.547e{-}07)p^4+(0.000252)p^3 \\ & +(-0.02722)p^2+(1.238)p+(77.13), \end{aligned} \tag{7}$$

where $\eta_{\text{DC–DC}}(p)$ efficiency of DC–DC converter and p is the percentage loading.

Similar procedure is adopted for the rest of the converters. DC–AC converter proposed by [40] is used. The efficiency of the converter as a function of loading is presented in (8). Since in case of DC system, the VSD loads have to go through one conversion stage i.e., DC–AC, same converter expression of (8) is used in (9) to define the efficiency of VSD converter.

$$\begin{aligned} \eta_{\text{DC–AC}}(p) = {} & (-9.95e{-}07)p^4+(0.0002871)p^3 \\ & +(-0.03052)p^2+(1.436)p+(63.79), \end{aligned} \tag{8}$$

$$\begin{aligned} \eta_{\text{VS DC}}(p) = {} & (-9.95e{-}07)p^4+(0.0002871)p^3 \\ & +(-0.03052)p^2+(1.436)p+(63.79), \end{aligned} \tag{9}$$

where $\eta_{\text{DC–AC}}(p)$ and $\eta_{\text{VSDC}}(p)$ are the efficiency of DC–AC converter, VSD converter and converter percentage loading respectively.

The input power including the converter loss of D category of loads can be calculated using (10)

$$p_{\text{D–BB}}(t) = \sum_{i=1}^{n1} \frac{p_{D-i}(t)}{\eta_{\text{DC-DC}-i}}, \tag{10}$$

where $p_{\text{D–BB1}}(t)$ is the power demand of the 'D' category loads in a BB; encompassing the load demand as well as the converter loss; and $n1$ represents the number of loads in the D category.

Similarly, power demand of A, VSD and I category loads can be calculated using (11) to (13) respectively.

$$p_{\text{A–BB}}(t) = \sum_{i=1}^{n2} \frac{p_{\text{AC}-i}(t)}{\eta_{\text{DC–DC}-i}}, \tag{11}$$

$$p_{\text{VSD–BB}}(t) = \sum_{i=1}^{n3} \frac{p_{\text{VSD}-i}(t)}{\eta_{\text{DC–DC}-i}}, \tag{12}$$

$$p_{\text{I–BB}}(t) = \sum_{i=1}^{n4} p_{\text{I}-i}(t), \tag{13}$$

where $p_{\text{AC–BB}}(t)$, $p_{\text{VSD–BB}}(t)$ and $p_{\text{I–BB}}(t)$ is the power demand of the A, VSD and I category loads in a BB encompassing the converter loss as well, respectively. Similarly, $n2$, $n3$, and $n4$ represent the number of AC, VSD and I category loads, respectively.

The instantaneous load demand of the BB is the sum of all the loads combined, as presented in (14)

$$\begin{aligned} p_{\text{load–BB}}(t) = {} & p_{\text{A–BB}}(t)+p_{\text{D-BB}}(t) \\ & +p_{\text{VSD–BB}}(t)+p_{\text{I-BB}}(t). \end{aligned} \tag{14}$$

The power from solar PVs requires a DC–DC conversion therefore a DC–DC PEC of (7) is employed for the purpose. The output of the solar PV undergoes a conversion and then delivers power to the BB, mathematically presented in (15)

$$p_{\text{solar-DCBB}}(t) = \eta_{\text{DC–DC}}(p)p_{\text{solar-BB}}(t). \tag{15}$$

The net power which is taken from the utility grid is the difference of (14) and (15), presented in (16).

$$p_{\text{BB-grid}}(t) = p_{\text{load-BB}}(t) - p_{\text{solar-DCBB}}(t). \tag{16}$$

Since the aim of this research is to find the BB efficiency, which can be calculated from the ratio of the total load demand of the BB to the total input power to the BB. The total input power to the BB is the sum of power from the utility grid and solar PVs installed at the rooftop as presented in (17). And the efficiency can then be found by utilizing the ratio of powers, mathematically shown in (18).

$$p_{\text{in-BB1}}(t) = p_{\text{BB-grid1}}(t) + p_{\text{solar-BB1}}(t), \tag{17}$$

$$DCBB_{\text{efficiency}}(t) = \frac{p_{\text{load1}}(t)}{p_{\text{in-BB1}}(t)}, \tag{18}$$

where represents the efficiency of DC BB. In order to find the efficiency of the AC BB, similar equations are derived with few exceptions such as:

- AC–DC conversion is employed for D category loads by making use of the AC–DC converter presented in [41].
- For VSD loads, the combination of AC–DC and DC–AC conversion stages is employed.

5. Efficiency comparison: AC vs DC

The comparison of AC and DC BB efficiency is established considering the parameter of the time of day, and the associated parameters of daily load variation as well as irradiance variation throughout the day. The comparative efficiency curve against the data of the month of May is presented in Fig. 4. On the basis of observation, the curves in the figure may be divided into three time zones (TZ); TZ1 is from midnight to 06:00, TZ2 is from 06:00 to 15:00 and TZ3 is from 15:00 till midnight. In TZ1 and TZ3 the efficiency of AC BB is more than the DC BB while in TZ2 the efficiency of DC BB is more than the AC BB. The reason is the availability of solar during TZ2.

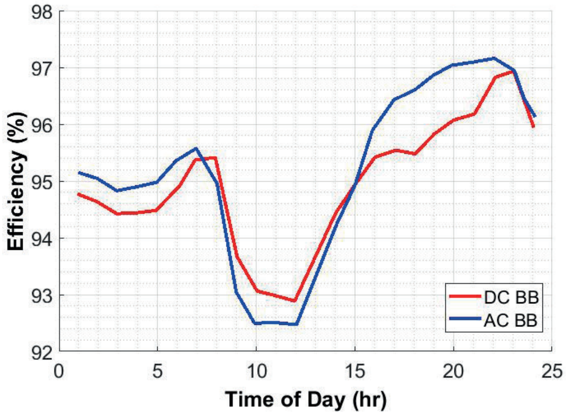

Fig. 4. Efficiency comparison of AC and DC BB

6. Sensitivity analysis

In order to present a comprehensive analysis, the effect of each parameter is dealt separately. Efficiency analysis is made by:

- varying the solar capacity,
- varying the PECs efficiency,
- varying the proportion of VSD loads,
- utilizing load curves of various months to account the seasonal effect.

6.1. Solar capacity variation. The solar capacity in a BB is increased from zero to 500 W and 1000 W. The results are compared with the presented in Fig. 5. Without solar capacity, the DC BB shows quite lower efficiency values as compared to AC BB. However, the efficiency difference falls as solar capacity in increased. Therefore, it can be said that solar capacity favors DC BB efficiency. Furthermore, during TZ2, it can be observed that DC BB shows better efficiency values as compared to AC BB. However, there is another important point that is against the conventional thinking of better efficiency of DC BB with increased solar capacity. It can be seen that the efficiency of DC BB is better during TZ2 *without* solar PV installed. During noon, the efficiency of both BBs is equal when there is no supply from solar PVs and then the efficiency of the DC BB falls as the solar capacity is increased. Similar efficiency falling trend can be observed for the case of AC BB. The reason of this reduction in efficiency is related to the efficiency of the PEC installed with the solar PVs; DC–DC in case of DC BB and DC–AC in case of AC BB. The PEC attached to a higher input and driving a load at a relatively lower demand as compared to the input operates at a lower efficiency. When the installed

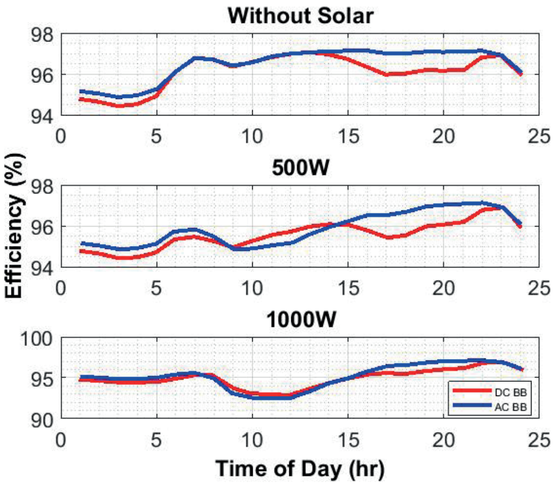

Fig. 5. AC vs DC BB efficiency for various solar capacities

capacity is increased, the same loads are driven at a lower PEC efficiency resulting in the overall drop in efficiency of the BBs.

6.2. Variation of VSD operated load. As the proportion of VSD loads is increased in the system, the efficiency of DC BB becomes more than the AC BB throughout the day. This variation is shown in Fig. 6. Approximately 2% increase in the efficiency of DC BB efficiency is observed when all the AC loads are operated through VSD. Hence, the modern trend of VSD loads is a confirm vote for DC BB. It is important to point out here that the efficiency of DC has not increased except during TZ3. However, the efficiency of AC BB has dropped throughout the day because during 50-50 proportion of the loads among A and VCD, the A loads are driven directly in AC BB, without any conversion stage. However, in case of VSD, the same loads have to go through two conversion stages resulting in the decrease in efficiency.

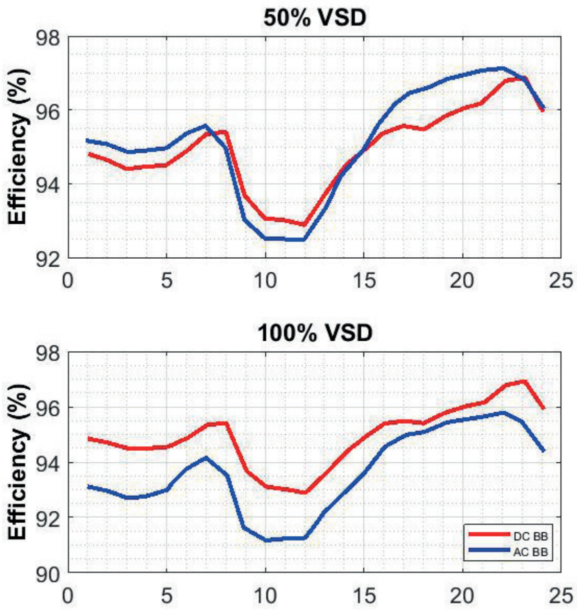

Fig. 6. AC vs DC BB efficiency for varying VSD penetration

6.3. Variation in the PECs efficiency curves.

- **DC–DC Converter:**

Sensitivity analysis of AC and DC BB efficiencies is carried out by varying the efficiency curves of DC-DC converters in small proportions. The results are pictorially presented in Fig. 7. It can be observed that when the efficiency of DC-DC converter is decreased by 2%, the efficiency of DC BB decreases by almost 1%. Similarly, when the efficiency of DC-DC converter is increased by 2% then the efficiency of DC BB improves with the effect being more prominent during TZ2. This is due to the fact that during TZ2, the PECs are lightly loaded and the efficiency values are lower. However, an increase in the efficiency values of the PECs during TZ2 presents fruitful results with a direct impact on DC BB efficiency. The efficiency of AC BB remains unaffected because of the absence of DC-DC converter.

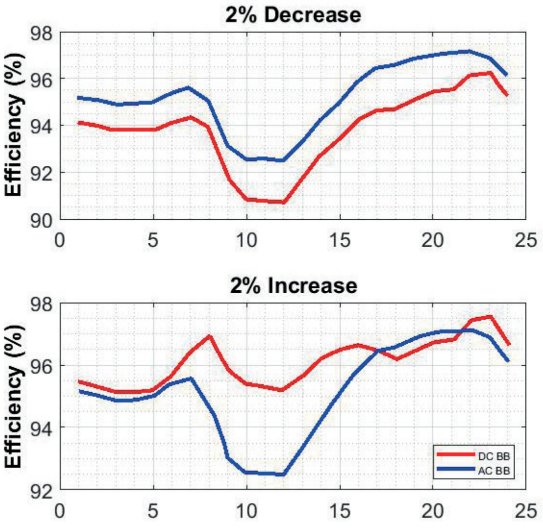

Fig. 7. AC vs DC BB efficiency for varying DC-DC converter efficiency

- **AC–DC Converter:**

In this case the efficiency of AC-DC converter is varied by 2% with rest of the parameters kept constant. When the efficiency of AC-DC converter is lowered by 2%; the efficiency of AC BB decreases by almost 1%. A similar trend of increase in AC BB efficiency is observed when the efficiency of AC-DC converter is increased by 2%. The effect is presented in Fig. 8.

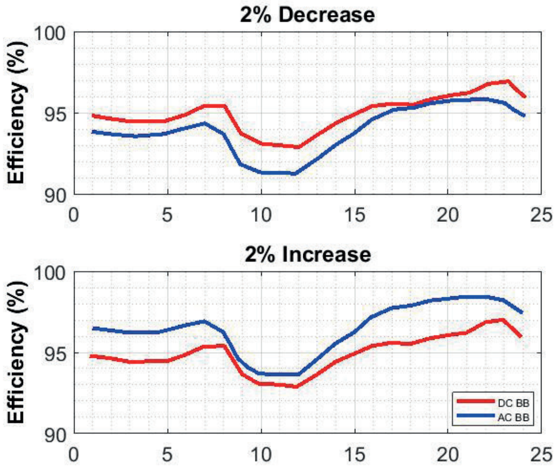

Fig. 8. AC vs DC BB efficiency for varying AC-DC converter efficiency

- **DC–AC Converter:**

In comparison to the other PECs, DC–AC converter is present in both AC and DC BBs. When the efficiency of DC–AC converter is decreased by 2%; the efficiencies of both AC and DC BBs decrease by almost 1%. Similarly, when the efficiency of DC–AC converter is improved by 2%; the efficiencies of both the AC and DC BBs increase but the improvement in AC BB is more in TZ2. This is due to the fact that the power output from the solar PVs, which undergoes conversion from DC–AC via DC–AC converter, increases duringTZ2. The variation of system efficiencies due to the variation in DC–AC converter efficiency curves is presented in Fig. 9.

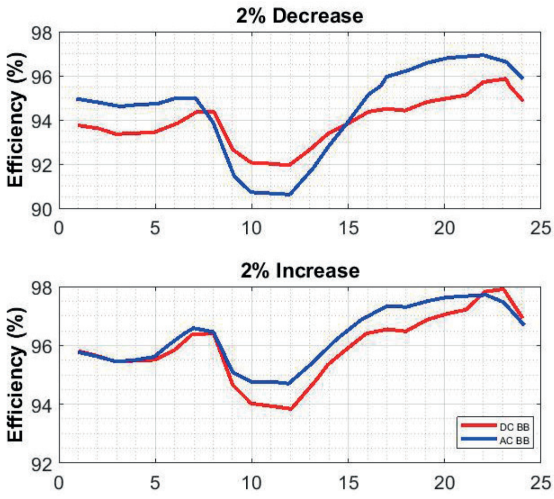

Fig. 9. AC vs DC BB efficiency for varying DC–AC converter efficiency

6.4. Variation in time of year. An important reason for choosing Berkeley CA, USA for the analyses is that the weather conditions of Berkeley present a variety of scenarios. The sun is available for 265 days in a year. Berkeley experiences summers during May and June, winters during December and January, and comparatively pleasant weather during rest of the year particularly during August, September and October. In order to include the effect of seasonal variations, the daily load variations as well as the solar irradiation data for odd months of the year are considered. The results of comparative efficiencies during odd months are presented in the Fig. 10.

The efficiency of DC BB is better as compared to AC BB during TZ2. The difference is more pronounced during colder months which may be thought as the opposite to what is expected because during colder months the solar irradiation is limited, still DC (conventionally favored by solar PVs) is presenting better efficiency values. However, the actual reason lies in the expression of efficiency. The efficiency is in inverse relation to the input. During lesser solar input, the majority or whole of it is utilized in driving the loads; thereby presenting better efficiency values.

During the months experiencing summer season, AC and DC BBs present a comparable picture during TZ1 and TZ2 overall. The AC BB presents better efficiency during TZ1 and DC BB takes almost the same lead during TZ2. However, before midnight in TZ3: the efficiency of DC BB tries to get beyond AC BB in May, succeeds in getting better efficiency during July and September, and then again AC BB takes the lead as weather approaches to winters. The reason of this trend can be attributed to the use of air-conditioning system which is operational during summer and contributes towards most of the power demand in a residential BB during TZ3. Since half of it is assumed to be operating through VSD which utilizes single conversion stage in case of DC and two conversion stages in case of AC resulting in providing a boost to the DC BB efficiency as compared to AC. Moreover, the period comprising between of July towards September which is a comparatively hotter period of the year in Berkeley, the power demand due to the air-conditioners increases resulting in the loading of the PECs near to their rated value. This makes the PECs to operate at better efficiency resulting in an overall increase of DC BB efficiency.

The month of March presents a haphazard picture. However, it can be observed that the overall efficiencies throughout the day seem comparable. The DC BB taking lead during TZ1.

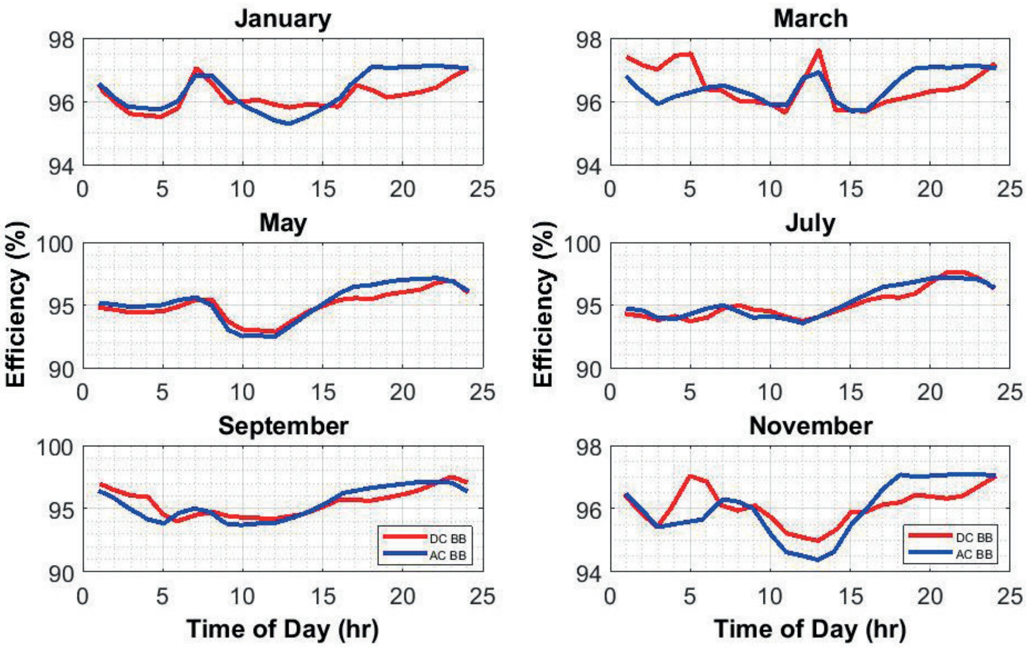

Fig. 10. AC vs DC BB Efficiency for various months

Similarly, the AC BB taking equivalent lead during TZ3. And during TZ2, the DC and AC efficiencies are almost comparable with AC BB taking minor lead for the most part.

7. Conclusion and future recommendation

The current research work is an effort to present a detailed comparison of the efficiency of residential BB for AC and DC distributions by considering a typical Berkeley CA, USA home. The comparative analyses are performed by encompassing the factors that affect the efficiency of the BBs. The results reveal that the efficiencies of both AC and DC BBs vary with the variation in the efficiencies of the installed PECs, penetration of VSD loads, solar capacities and seasonal conditions. From the point of view of comparison, the efficiency of DC BB improves with the solar capacity. However, the independent efficiencies of AC as well as DC BBs reduce as a result of increase in solar capacity. As regards to the efficiencies of both AC and DC, BBs present a direct relation with the efficiencies of the installed PECs. Increasing the efficiency of a PEC in a BB resulted in the increase of efficiency of the respective BB. The penetration of VSD loads is a direct vote for the DC BB efficiency. As far as seasonal effect is concerned, the DC BB presents better efficiency around noon throughout the year, as compared to AC BB. In contrast AC BB shows better efficiency values for rest of the day over the year.

The current research work can be utilized as base case, as it provides an insight to the effect of the parameters of PECs, solar, load type and seasonal conditions on the efficiencies of AC and DC BBs. The work can be extended to realize the conditions for which DC can be a better choice as compared to AC or vice versa. The boundary conditions can be defined that within the stated limits or under specific conditions the efficiency of one system is better than the other.

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