Turkish Online Journal of Qualitative Inquiry (TOJQI)
Volume 12, Issue 7, June 2021: 14145-14156

Residential DC Bus System for Maximizing Energy Efficiency

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Abstract

In a world that is constantly moving towards digitalization and electronics, it is to be noted that they are powered by DC supply. In our current residential system, however, we are using AC supply for powering majority of the motoring loads and few heating loads. We are using the same AC supply for powering DC appliances such as laptops, LED TVs, mobile phones, etc. In a house without inverter, this might seem to be a right way of powering the devices. On the other hand, in a house with inverter and power back up provision, a lot of power is wasted when energy is converted from one form to another multiple times. Considering the nature of power supply, we would be having in the future from renewable energy systems, we are forced to shift from AC residential distribution system to DC residential distribution system. Converters that have same nature of power supplies at the input as well as the output ends are more efficient than that of converters that have different nature of power supplies at the ends. With no doubt in the future, the AC motors we are using in our home appliances will also be replaced with BLDC motors. Our project deals with the study of how efficiently DC residential systems work when compared with AC residential systems. We also come forward with an idea that could help appliance manufacturers to switch to the new trend of DC distribution system. Apart from this, cost analysis has also been made comparing the present system and proposed system.

Keywords: Residential Distribution, DC system, Renewable Energy Systems, DC distribution, DC-DC Converters, Solar PV System

1. Introduction

Various engineers and scientists developed DC systems and AC systems simultaneously ever since electricity emerged as a form of energy. From an engineer's point of view, DC systems are not only easy to analyse but also easy to handle and are more efficient compared to AC systems. When dealing with AC systems, one has to worry about various factors such as frequency, phase sequence, phase difference etc. Also, phenomenon such as inductance and capacitance play major roles in AC systems. When it comes to AC transmission, a major part of the current carrying conductor is unavailable due to skin effect. This reduces the overall cross-sectional area of the conductor thus increasing its effective resistance. Unlike AC systems, DC systems are quite easy to handle. All the demerits of AC systems discussed above are overcome by DC systems. DC systems are inevitable in today's world filled with electronics. It is astonishing to realize that except those appliances involving motors such as washing machines, air-conditioners and ceiling fans, all other appliances in our residence such as laptops, LED TVs, mobile phones, LED lights, etc require DC power for operation. At present, in a house having no inverter, this might seem efficient because AC to DC conversion takes place only once. The main idea of this paper is to discuss the possibility of keeping a common Converter for all the DC devices thus converting the AC supply to DC supply just once and then feeding it into DC devices. Minimising the number of converters existing in a system will minimise the losses in the system. This will greatly help us to increase the efficiency thus saving energy. The main conceptual disadvantage in existing system is that when converters are cascaded, the net efficiency of the system is lesser than the efficiency of the least efficient system. Thus, there are strong arguments in favour of reducing the number of converters in the system. Moreover, AC to DC and DC to AC converters exhibit poor efficiencies than that of DC to DC and AC to AC converters. In the presence of Solar PV systems, the generated power itself is in DC nature. Under such circumstances, the power shall be directly fed to DC appliances in our homes without unnecessarily converting them into AC in between.

The discussion of the topics is as follows. The existing system in a household that uses inverter and a battery for power back-up is discussed first, followed by the system we propose. Both these systems are connected with the grid i.e., they draw 100% power from the grid. As a result, the supply to these systems is alternating in nature. The third system, however, is considered to be a standalone system powered by Solar PV panel. The mathematical analysis is carried out for each of these systems with the help of MATLAB Simulink followed by the running cost estimation of the first two systems. At last, an idea to revolutionize the DC distribution system is also provided taking a home appliance as example.

2. Mathematical Analysis of Systems

1. Existing System

A. Block Diagram:

The block diagram of the existing system is shown in fig.1. This block diagram gives an idea of the existing AC system that is used in residential distribution and its functionality. Consider, a home inverter circuit which is supplied by a 230V, 50Hz AC supply. In the presence of an inverter in the system several conversions take place before supplying energy to the appliances as shown in the figure, i.e., first rectification followed by inversion and then it is supplied it to the appliances.

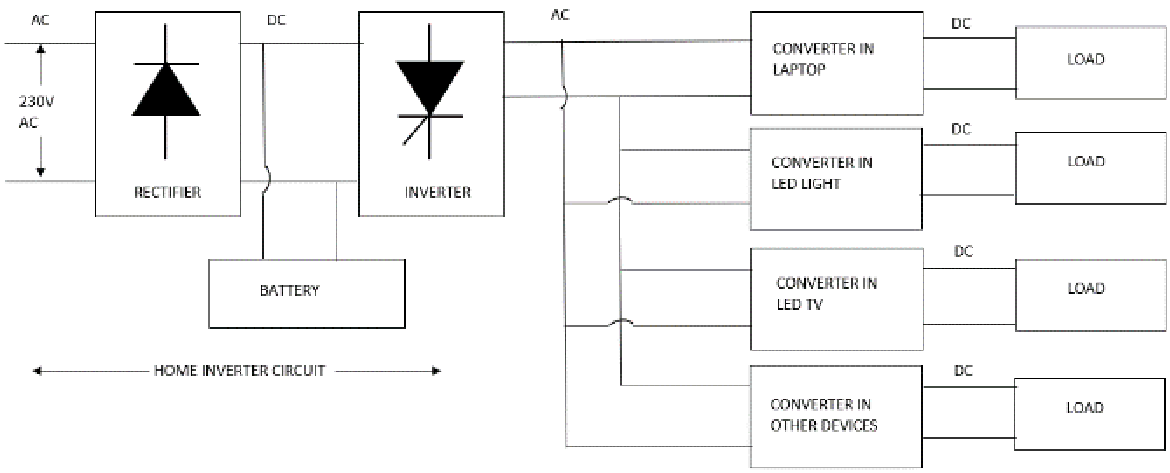

Fig. 1. Block diagram of Existing System

B. Operation of Existing System

At first, the 230V, 50Hz AC supply is given to the rectifier. At first, rectification process takes place in the circuit for conversion of AC (Alternating Current) power to DC (Direct Current) power for storing the DC power in a battery. From the battery the DC power will flow to the inverter circuit where the inversion process happens. The DC power will be converted again into AC power and is supplied to the appliances. Since, most of the appliances in our home such as LED TV, LED lights, Mobile Phone, Laptop and other appliances are all running on DC power. We are getting AC supply to our home and these appliances can run only on DC supply. As a result, once again internally or externally there will be a conversion process taking place thus converting AC supply to DC supply for its proper working. It could be observed that, there are 2 to 3 conversion processes happening for some of the household appliances to work. Thus, conversion of power from one state to another state i.e., from AC power to DC power will reduce the efficiency of the appliance and there will be power loss on each conversion process.

C. MATLAB Simulation

As explained in the block diagram, the existing system has a rectifier, a battery for storing power and an inverter. When it comes to home inverter circuits, in the presence of power supply from the grid, the battery is charged parallelly while providing supply to the home appliances. As a result, the entire inverter system is by-passed. In the absence of power supply from the grid, the battery is connected to the appliances through an inverter. Thus, an interlock static switch mechanism is present inside inverters that enable only one operation at a time.

In this project work, since we are concerned about the converter efficiencies more rather than about the way in which they work, we choose to carry out the simulation by neglecting the interlock switching mechanism thus avoiding unnecessary complications. The MATLAB Simulink circuit for the existing system is shown in fig.2.

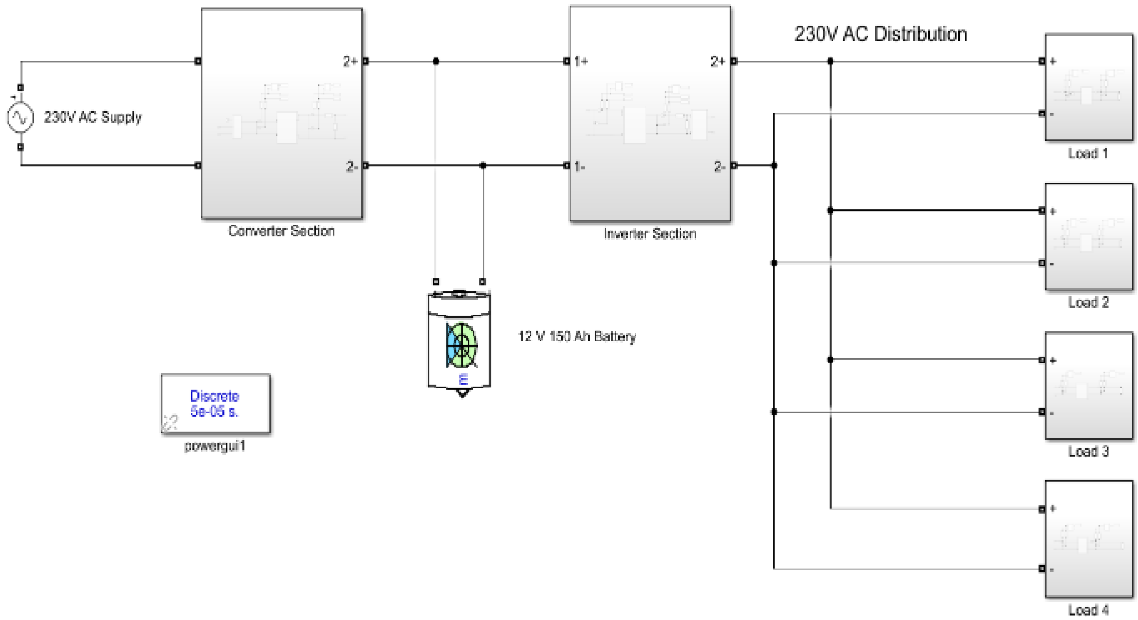

Fig. 2. MATLAB Simulink Circuit of Existing System

At last, Voltage Measurement blocks and Current Measurement Blocks are added in required places of the circuit. The input power and output power of each converter is measured by using the Power Measurement block. Since AC voltages are also measured, RMS block is used to compute the DC equivalent of the AC parameters from which power is calculated. With the use of input power and output power at each stage, efficiencies of the corresponding converters are also determined.

D. Efficiency Calculation

To supply any one of the connected DC appliances, the power has to flow from the grid through the converter, inverter and through the individual equipment rectifier. Thus, there are three conversion processes taking place.

Let us consider one path of power flow to obtain the overall efficiency of the system from the source to any one load. The power flow from the grid to Laptop is shown in fig.3.

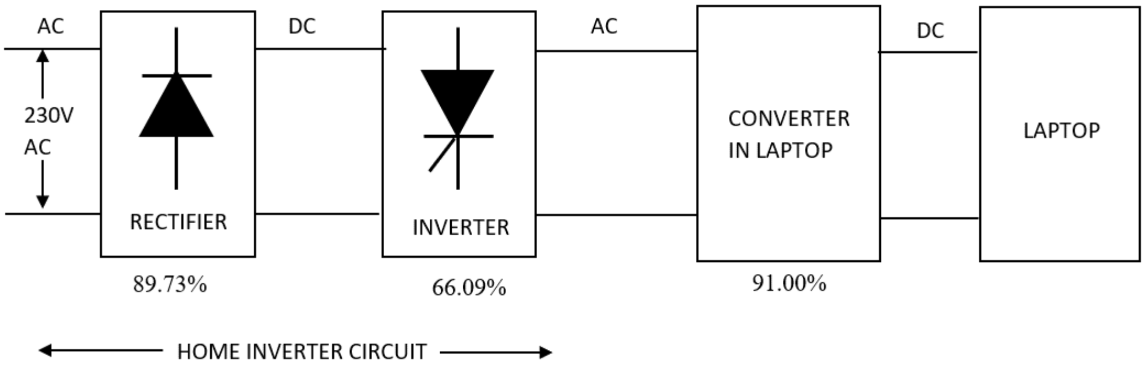

Fig.3. Power flow in Existing System

Rectifier efficiency, η_1= 89.73%

Inverter efficiency, η_2= 66.09%

Laptop Charger efficiency, η_3= 91.00%

Hence, the net efficiency of the system is given by,

$\eta_{eq} = \eta_1 \times \eta_2 \times \eta_3$

$= 0.8973 \times 0.6609 \times 0.9100$

$= 0.5396$

As a result,

$\eta_{eq} = 53.96\%$

The efficiencies are calculated from the values of input and output power of each converter from the MATLAB Simulation. The values of efficiencies thus calculated are tabulated in Table I.

SL. No.	COMPONENT	INPUT POWER (W)	OUTPUT POWER (W)	EFFICIENCY (%)
1.	Rectifier	438.5	393.5	89.73
2.	Inverter	204.4	135.1	66.09
3.	Laptop Charger	109.6	99.74	91.00
4.	LED TV Converter Circuit	78.91	71.84	90.04
5.	Mobile Phone Charger	9.345	6.045	64.68
6.	Trimmer Converter Circuit	2.807	1.817	64.73

Table I. Efficiencies of Converters in Existing System

2. Proposed System – I

A. Block Diagram

The block diagram of the proposed system is shown in fig.4. This block diagram gives an idea of a proposed system that can be used in residential system thereby improving efficiency and reducing power loss.

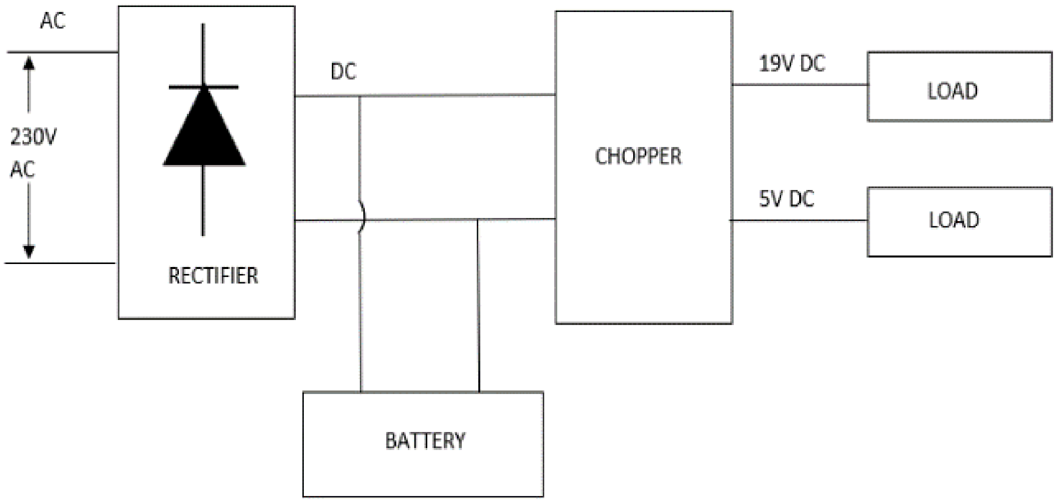

Fig.4. Block Diagram of Proposed System - I

In this system, there will be no inversion process and there will be only rectification process and chopping process and is supplied to the load.

B. Operation of Proposed System – I (Grid Connected)

At first, the 230V,50Hz AC supply is given to the rectifier. There will be a rectification process happening in the circuit for conversion of AC (Alternating Current) power to DC (Direct Current) power for storing the converted DC power in a battery. The AC-DC conversion is carried out using a transformer-rectifier unit. The AC supply obtained from the grid is converted into appropriate DC voltage level for charging the battery. From the battery the DC power will flow to the chopper circuit where the voltage can be stepped up using Boost Converter up to a voltage of about 19V or stepped down using Buck converter up to a voltage of 5V and the chopped voltages is directly given to the appliances based on the voltage rating of each appliances. By this proposed method we will have only one conversion process of converting power from AC power to DC power at only at the input side where there will be not furthermore conversion process and thereby increasing the efficiency of the system and thereby reducing the losses due to conversion.

C. MATLAB Simulation

Like the first circuit, the grid is represented by a 230V AC Voltage Source. The converted DC voltage is then fed into a Buck and Boost Converter for stepping down and stepping up the DC voltage respectively.

The Boost Converter uses a 1mH inductor, a 33μF capacitor, a power Diode and MOSFET as a static switch. The switching frequency of MOSFET is 5kHz. The duty cycle is 15.6%.

The Buck Converter uses a 1mH inductor, a 220μF capacitor, a power Diode and MOSFET as a static switch operating at a switching frequency of 10kHz with a duty cycle of 37.45%.

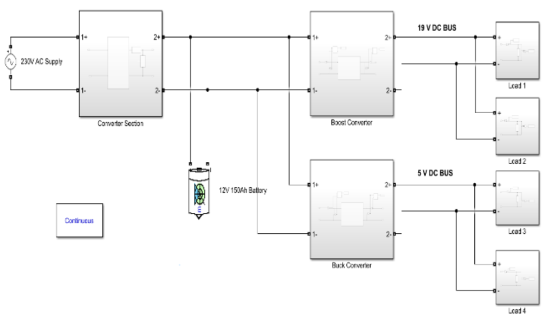

Fig.5. MATLAB Simulink Circuit of Proposed System – I

D. Efficiency Calculation

To supply any one of the connected DC appliances, the power must flow from the grid through the AC-DC converter first. Then the power must flow through the Buck and Boost Converter to reach the DC appliances of appropriate voltage levels. Thus, there are two conversion processes taking place and not three. This is because at the end of AC-DC Conversion, power will flow either through Buck Converter or through Boost Converter.

Let us consider one path of power flow to obtain the overall efficiency of the system from the source to any one load. The power flow from the grid to Laptop is shown in fig.6.

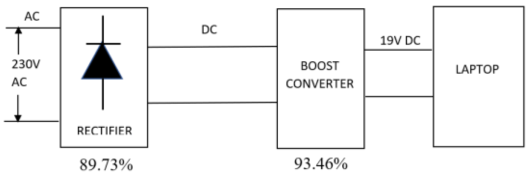

Fig.6. Power flow in Proposed System (Grid Connected)

Rectifier efficiency, η_1= 89.73%

Boost Converter efficiency, $\eta_{2=}$ 93.46%

Hence, the net efficiency of the system is given by,

$\eta_{eq} = \eta_1 \; x \; \eta_2$

$= 0.8973 \text{ x } 0.9346$

$= 0.8386$

As a result,

η_{eq} = 83.86%

The efficiencies are calculated from the values of input and output power of each converter from the MATLAB Simulation. The values of efficiencies thus calculated are tabulated in Table II.

SL. No.	COMPONENT	INPUT POWER (W)	OUTPUT POWER (W)	EFFICIENCY (%)
1.	Rectifier	438.5	393.5	89.73
2.	Boost Converter	92.71	86.65	93.46
3.	Buck Converter	26.91	23.78	88.36

Table II. Efficiencies of Converters in Proposed System – I

3. Proposed System – II (Solar Pv Standalone System)

A. Block Diagram

The block diagram of the Renewable (Solar PV) Based system is shown in fig.7. This block diagram gives an idea of a Renewable system that can be used in residential system and thus improvement in efficiency.

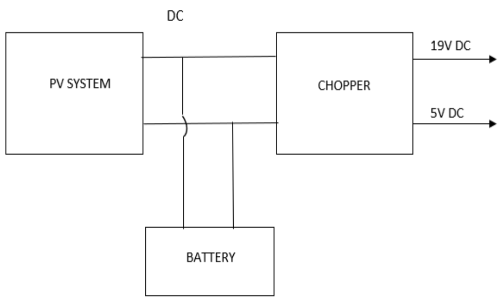

Fig.7. Block Diagram of Proposed System - II

This Renewable system method is another type of source that can be used in residential system where there is no involvement of conversion process of converting AC power to DC power and can be directly supplied to the appliances.

B. Operation of Proposed System – II

This process is done with the help of PV panel where several solar cells are interconnected to produce DC power which generated with the help of sunlight. After the generation of DC power from the PV panel the DC power is stored in a battery. From there the DC power will directly flow through the chopper circuit without any inversion process of converting DC power to AC power. The direct DC power from the PV panel is fed to the chopper circuit where the voltage can be stepped up using Boost Converter to a voltage of about 19V or stepped down using Buck converter to a voltage of 5V and the chopped voltages is directly given to the appliances based on the voltage rating of each appliances.

By this method, the system eliminates the conversion process which improves the overall efficiency of the system and thereby reducing losses in the system.

C. MATLAB Simulation

The overall diagram of the system is shown in fig.8.

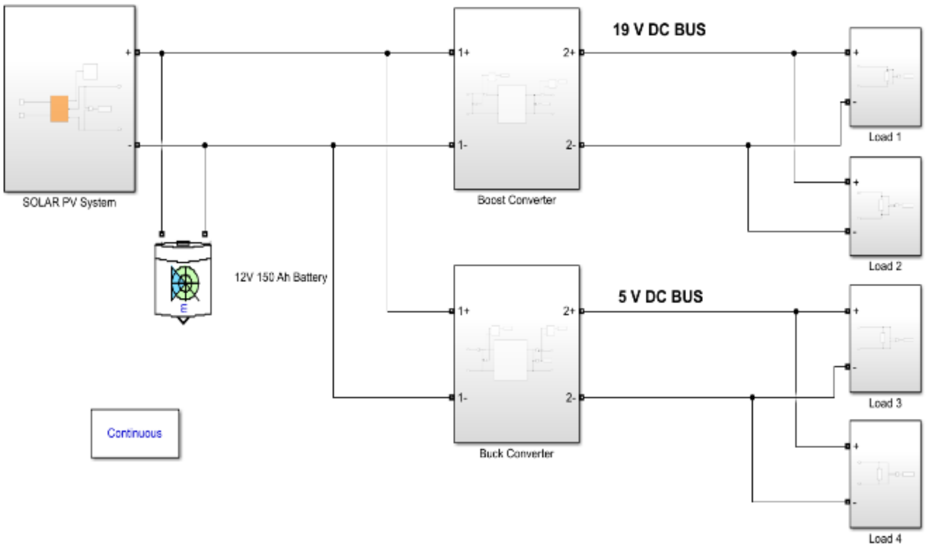

Fig.8. MATLAB Simulink Circuit of Proposed System - II

For simulating solar PV system for residential purposes, PV Array block from Simulink is used with an Irradiation of 1000 W/m^2 and Temperature of 70^0 C. The output voltage of the Solar PV array is in an intermediate level between 5V DC and 19V DC to charge the battery. Hence, just as in the previous case, a Boost Converter is used to step up the DC voltage into 19V while a Buck Converter is used to step down the DC voltage into 5V.

The loads are connected to the outputs of the appropriate converters. Power measurement blocks are connected before and after each converter to enable the calculation of efficiency.

D. Efficiency Calculation

In this system, to supply any one of the DC systems, the power from the Solar PV System will flow through a DC-DC converter and directly reaches the load. If the output voltage of the solar PV system is to be stepped up, then power will flow through the Boost Converter. If the output voltage is to be stepped down, then it will flow through the Buck Converter.

If efficiency is calculated for one power flow path from the source to load, it could be seen that conversion process takes place only once (and that too does not involve conversion from AC to DC or DC to AC).

The efficiency of the Boost Converter is very high and hence, power loss is minimized to a very great extent.

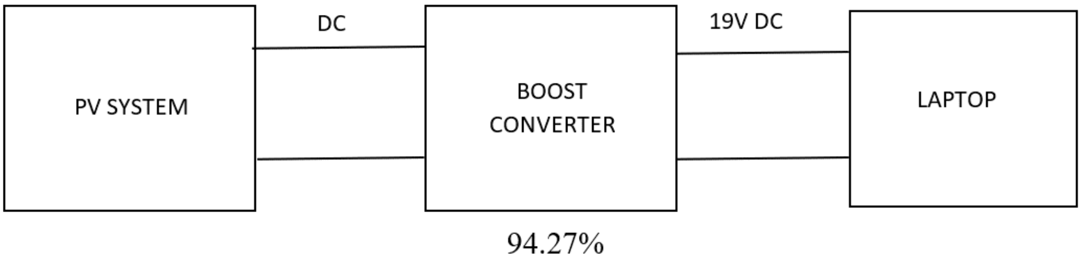

Fig.9. Power flow in Solar PV powered system

Boost converter efficiency, η = 94.27%

Since there is only one converter, the net efficiency of the system will be equal to the efficiency of that converter.

As a result,

η_{eq} = 94.27%

The efficiencies are calculated from the values of input and output power of each converter from the MATLAB Simulation. The values of efficiencies thus calculated are tabulated in Table.

SL. No.	COMPONENT	INPUT POWER (W)	OUTPUT POWER (W)	EFFICIENCY (%)
1.	Boost Converter	101.4	95.59	94.27
2.	Buck Converter	26.64	23.3	87.46

Table III. Efficiencies of Converters in Proposed System - II

3. Running Cost Estimation

The running cost analysis of existing system and Proposed System I is being discussed here. The running cost comparison can be made only among these two systems since it is connected with the grid and since consumers have to pay it to the electricity board. In Proposed System II, since standalone system is discussed, such an analysis on tariff cannot be made.

A. Running Cost in Existing System

In the existing system, we saw that the efficiency came out to be 53.96%. However, the load demand of the appliances connected will be constant. As a result, poor efficiency of the system will draw more power from the grid.

Total load connected = Output Power of the system = 281.4 W

Efficiency of existing system, η = 53.96%

Input power drawn from the grid = $\frac{Output\ Power}{\eta} = \frac{281.4}{0.5396}$ = 521.5 W

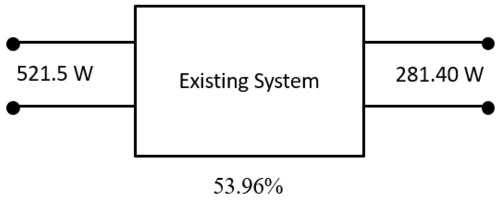

Fig.10. Existing System – Overall Diagram

For simplicity in analysis, it is assumed that each of those devices run for 10 hours a day.

Hence, Energy Consumed in a day = 5.125 kWh

The average cost per unit is assumed to be ₹ 6.09.

This would give us the following results:

Cost per day = ₹ 31.76

Cost per month = ₹ 952.78

Cost per year = ₹11,592.16

B. Running Cost in Proposed System

In Proposed System I, we saw that the overall efficiency of the system is 83.86%. In this case too, the load demand is same as that of in existing system. Since the efficiency of this system is better than the previous case, it draws comparatively less power from the system.

Total load connected = Output Power of the system = 281.4 W

Efficiency of existing system, η = 83.86%

Input power drawn from the grid =

$\frac{Output\ Power}{\eta} = \frac{281.4}{0.8386}$ = 335.56 W

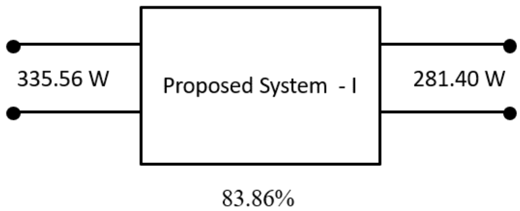

Fig.11. Proposed System I – Overall Diagram

For simplicity in analysis, it is assumed that each of those devices run for 10 hours a day.

Hence, Energy Consumed in a day =3.3556 kWh

The average cost per unit is assumed to be ₹ 6.09.

This would give us the following results:

Cost per day = ₹ 20.44

Cost per month = ₹ 613.07

Cost per year = ₹ 7459.00

4. Comparison in Terms Of Running Cost

The tables below show the running cost per day, per month and per year of both the systems.

System	1 Day	1 Month	1 Year
Existing System	₹ 31.76	₹ 952.78	₹11,592.16
Proposed System I	₹ 20.44	₹ 613.07	₹ 7,459.00

Table IV. Running Cost Estimation

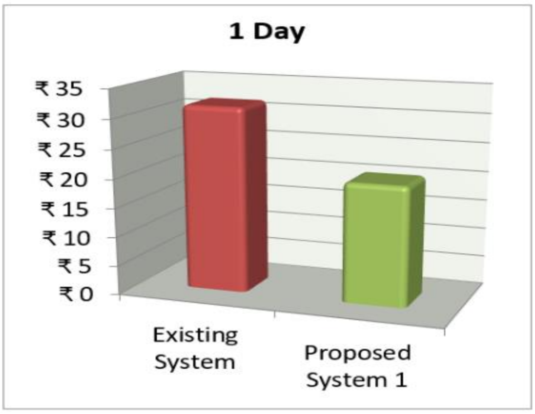

Fig.12. Graphical Comparison of Running Cost per day

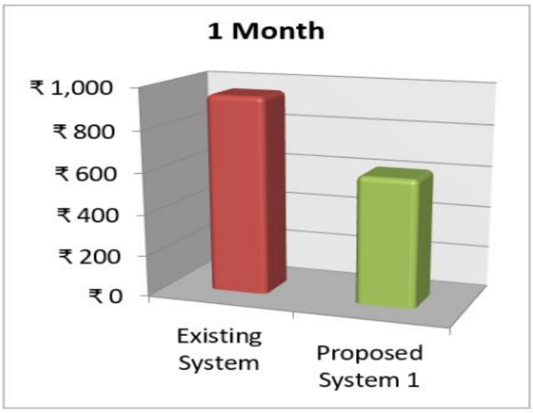

Fig.13. Graphical Comparison of Running Cost per month

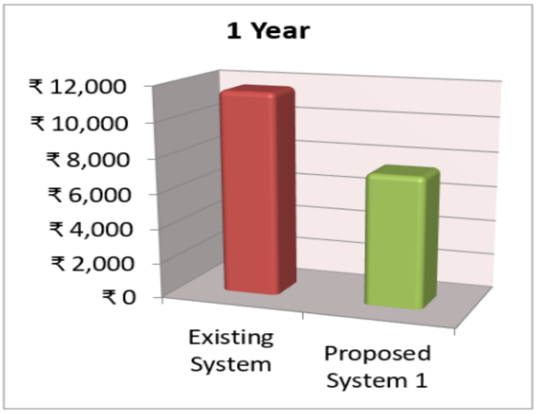

Fig.14. Graphical Comparison of Running Cost per year

5. Future Scope

It is clear from the above articles that to function in DC bus system, the appliances that are already working in AC supply should be compatible when supplied with DC supply.

For instance, in appliances such as LED TV (that has no power back-up facility) the AC-DC conversion takes place in an inbuilt circuit whereas in appliances such as Laptops and Mobile Phones (that has battery for power back-up), the AC-DC conversion takes place in the charger.

From the consumer point of view, the new system should be adaptable and should easily replace the existing system without any complications.

We came up with a solution to make this transition from AC system to DC system in a smooth way. Let us consider LED TV for example. It is an electronic component and it obviously works only in DC supply. Hence, there exists a circuit within the television that converts the 230V AC supply into DC supply which is then fed to the electronics system. It can be noticed that, after conversion, a DC transmission system is present which connects the rectifier output to the electronic circuitry.

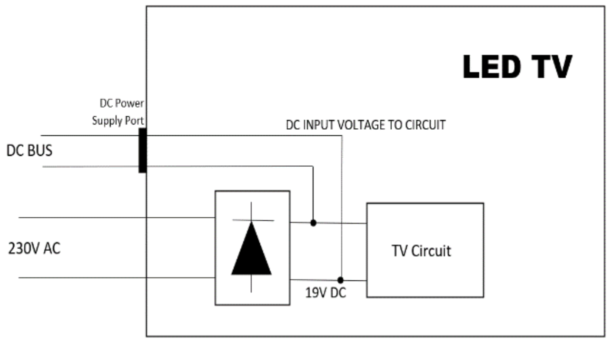

Fig.13. Additional provision for DC supply in LED TV

If this DC transmission system is made available as a port at the periphery of the television cabinet, then the power supply shall be directly provided to the electronic circuitry by-passing the AC-DC converter.

In simple words, if the LED TV circuit uses 19V DC for its functioning, then the 230V AC supply is converted into 19V DC in the presence of AC residential bus system. At present, the 19V DC terminals is not accessible from outside. If it is made accessible by providing an extra DC Power Supply Port then, 19V DC supply from the Boost Converter in our system shall be directly fed into the electronic circuitry.

This change is simple from manufacturing point of view. There is no need of changing the system entirely. All it requires is an additional port that connects the 19V system in the television directly to the residential DC bus.

However, the AC supply provision shall also be present. It might take a few years for every household to adapt to this system. In the meantime, customers with AC bus system in their house shall use the AC port in the television while customers with DC bus system shall use DC port.

6. Conclusion

From the results of our work, we can conclude that preferring a DC residential bus system over AC bus system is necessary as the nature of the source of the appliances we are using today, as well as the ones we will be using in the future will be changing from AC to DC. The process of switching from AC to DC might seem difficult in the beginning as both equipment and supply is adapted to work in AC supply. Once this change is adopted in DC appliances so as to directly fetch DC supply from residential DC system, we will be able to save considerable energy. During the transition time, the appliances will be having provision for both kinds of supply. However, in the long run, DC residential distribution system will completely take over AC system.

Moreover, as stated above, the future lies in the hand of renewable energy systems that provide DC supply.

Though the source of renewable energy is infinite, the extent to which we harvest it is always finite. Thus, it is our responsibility to utilize the harvested energy in a most efficient way..

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