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Performance Evaluation of DC Microgrid System for Residential LED Lighting Application

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Abstract – *This paper proposes LED lighting applications DC microgrid system with compact LED lamps system for residential. Conventionally, the residential lighting system used the supply from the authorized energy supplier to power up all the electrical appliances at home. In Malaysia, the voltage distributed to residential area is 240V AC. However, most of electrical appliances at home are not driven in AC. Therefore, the electrical appliances that driven by DC requires AC/DC converter to operate. But the conversion process of the converter creates losses due to the switching of the device. For these reasons, the use of low voltage direct current (LVDC) distribution is attracting interest. In order to reduce the losses, the design of direct current (DC) microgrid at residential is proposed. This research aims to compare conventional residential lighting systems with proposed residential lighting system. The comparison conducted by simulation using MATLAB Simulink and experiment. The simulations are carried out to illustrate the power consumption for all cases. The experiment set up to compare the performance of all cases in term of power consumption, luminance, and voltage and current harmonic. Furthermore, this experiment consider suitable wiring design of the proposed system includes size of cable. As the results, the proposed system shows the better performance than the conventional system.*

***Keywords**: DC Microgrid, Residential Lighting, LED, Green Technology*

I. Introduction

In recent years, along with continuous development of market economy and extension of industrial scale, more research undertaken to make the improvement on LED to replace current type of lamps for residential use such as incandescent and fluorescent [1].

That is because of it energy efficient characteristic [2]. Moreover, LED is DC driven device and the development in LED technology improved it efficiency and thermal problem to be better performance cooling methods using seebeck effect method [3]-[4].

Thus, in line with this lighting development, the research on expanding the application of renewable energy in residential is also in full swing [5]-[9].

The losses evaluation on DC and AC system for residential have been observes and the loss calculation result shows the total losses in DC system are 15% lower than the losses in AC system [10]. This paper proposes LED lighting applications DC microgrid system with compact LED lamps system for residential. Conventionally, the residential lighting system used the supply from the authorized energy supplier to power up all the electrical appliances at home. In Malaysia, the voltage distributed to residential area is 240V AC.

However, most of electrical appliances at home are not driven in AC. Therefore, the electrical appliances that driven by DC requires AC/DC converter to operate.

But the conversion process of the converter creates losses due to the switching of the device. For these reasons, the use of low voltage direct current (LVDC) distribution is attracting interest [11]-[14], [19]-[20].

In order to reduce the losses, the design of direct current (DC) microgrid at residential is proposed. This research aims to compare conventional residential lighting systems with proposed residential lighting system. The comparison conducted by simulation using MATLAB Simulink and experiment. The simulations are carried out to illustrate the power consumption for all cases.

The experiment set up to compare the performance of all cases in term of power consumption, luminance, and voltage and current harmonic. Furthermore, this experiment consider suitable wiring design of the proposed system includes size of cable. As the results, the proposed system shows the better performance than the conventional system.

II. Case Study Description

There are three case will be compared in this study which are 240V AC grid system with compact fluorescent lamps (CFLs), 240V AC grid system with compact LED lamps and proposed system. All cases are conduct for typical Malaysian double storey houses.

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Normally, each house has 22 lighting points as shown in Fig. 1 below where the ground floor and first floor has 11 lighting points. Hence, the simulation and experiment conducts for 22 lighting points also.

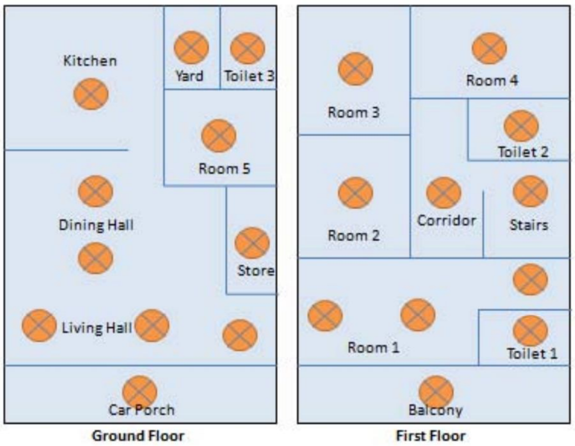

Fig. 1. Typical Malaysian double storey house plan layout

A. Case 1: 240V AC grid system with (CFLs)

Before the existence of LED as lighting for residential, CFL being the most used lamp and replacing the incandescent as residential lighting [1].

CFL are said as the best than incandescent and it is proven that CFL is more energy saving, because 25 watts CFL has equivalent lumen with 100 watts incandescent [15]. However, incandescent does have advantage over CFL such as during start up [16]. Incandescent can turn on instantly, but CFL takes time to warm up. Case 1 refers to the 240V AC grid system with CFLs as shown in Fig. 2. CFL does not require any converter in order to operate with supply from utility supply. This is the conventional residential lighting system apply in most houses.

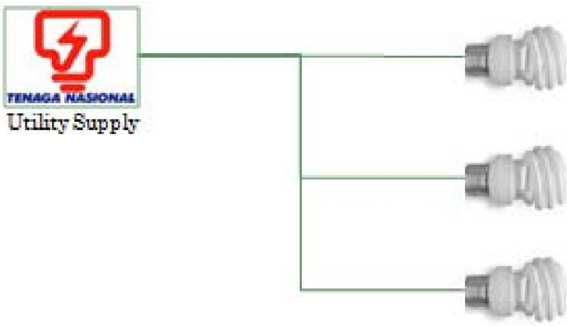

Fig. 2. 240V AC grid system with CFLs illustration diagram

B. Case 2: 240V AC grid system with compact LED lamps

As the lighting technology develops, solid state lighting SSL which is LED becomes better and better.

Now, more SSL type of lamp produces for the use in residential. Conventionally, to operate with AC supply the compact LED lamps requires it own driver to convert 240V AC to desired DC voltage of LED.

Fig. 3 shows illustration diagram for conventional residential lighting system 240V AC grid with compact LED lamps. The power rating of compact LED lamp is 12 watts because 12W of compact LED lamp has equivalent of lumen to 25W of CFL [15]. The existence of the converter prevents the LED from operates efficiently because of the losses in the converter. This is the conventional residential lighting system with compact LED lamps.

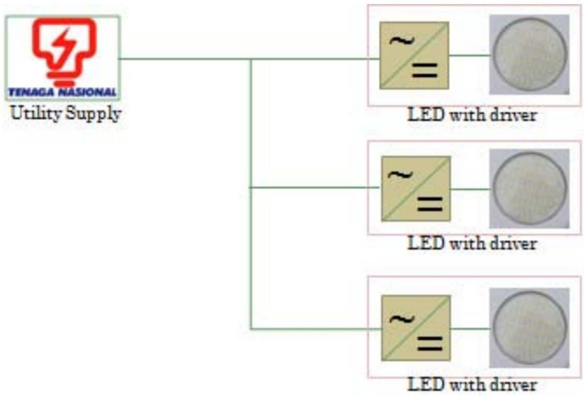

Fig. 3. 240V AC grid system with compact LED lamps illustration diagram

C. Case 3: Proposed system

Advantages in LED as DC driven device leads to the proposing of DC microgrid system for residential compact LED lamps applications.

The illustration diagram of proposed DC microgrid system with compact LED lamps shown in Fig. 4, this system proposed to improve the lighting system in residential to be more efficient in term of economic and performance.

From the figure, the amount of converter uses in every LED can be eliminates compared with 240V AC grid with compact LED lamps system. Only supply from utility connects with converter. In addition, the amount of losses that occurs from the conversion process also can be reduced. Hence, the compact LED lamps which DC driven device can be connected directly to the DC supply.

This study used MATLAB Simulink software for the simulation. Refers to Fig. 4, there are four main blocks consists in simulation model which are AC supply, DC supply, AC to DC converter and the loads.

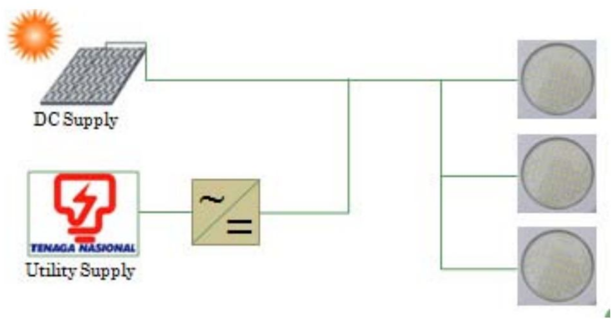

Fig. 4. Proposed system illustration diagram

According to Fig. 5 below the load receives two different type of supply. The loads used are compact LED lamps which operate with DC supply. Hence, the AC to DC converter applied at AC supply to get the DC supply for the loads.

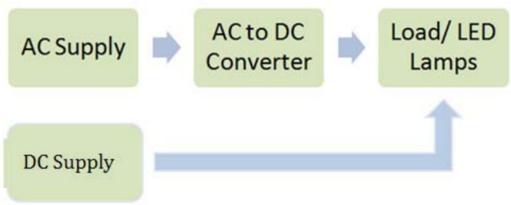

Fig. 5. Simulation block diagram

A. AC Supply

Standard AC supply for residential in Malaysia is 240V AC with 50Hz frequency. In the simulation, 240V AC supply available in the software. So, the component can simply import from the library.

B. DC Supply

This research proposes to use 12V DC for residential LED lamps application. In simulation, 12V DC imports from the library and inserts into the circuit.

C. AC to DC Converter

Electronic device that convert AC supply to DC supply required in this research for utility supply which conventionally used as the main supply, it also known as switching mode power supply (SMPS).

The modeling of AC to DC converter diagram using MATLAB Simulink, it is shown in Fig. 6. It consist of transformer to step down the voltage from 240V AC to 12V DC, diodes to allow current flowing in one direction, inductor and capacitor function as the circuit filter so that smooth DC voltage obtained.

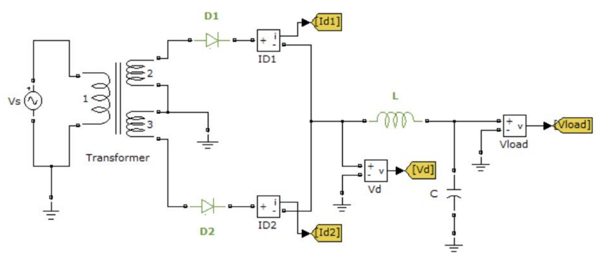

Fig. 6. Converter model

D. Loads

Proposed system recommends mainly for residential lighting application which applies compact LED lamps as the system loads. In MATLAB simulation, the loads replace with the resistor as shown in Fig. 7.

It is an example for load connection in this system. Refers to the figure there are three load branches. One branch indicates one lighting points where in this proposed system consists of 22 lighting points following the typical Malaysian standard of double stories houses.

The value of loads resistor calculates based on $P = \frac{V^2}{R}$ formulae. Besides, amount of resistance through the cable also taken into account in this research. The cable resistance depends on the length of the cable and calculated using particular formula for cable resistance.

The longer the cable length makes the resistance higher. The increasing of cable resistance leads to higher losses.

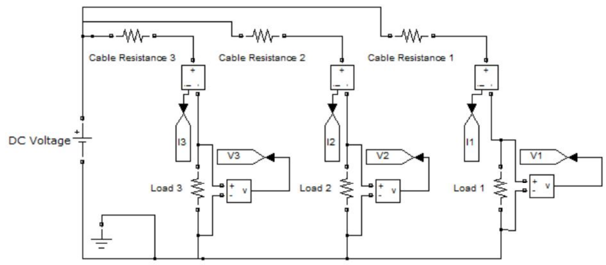

Fig. 7. Solar panel equivalent circuit

III. Simulation Analysis

A. Case 1: 240V AC grid system with compact fluorescent lamps (CFLs)

This studies carried out to make the comparison between all the three systems. Fig. 8 shows the system of grid 240V AC with CFLs simulation diagram. It is the residential conventional lighting system.

The conventional residential lighting system used CFL bulbs. Refers to the figure, the loads block connected directly to the 240V AC supply from utility.

The loads connection inside the block is the same as in Fig. 7, however, the load in Fig. 7 is use RLC branch as the load while in Fig. 8 used RLC load as the load. So, the value of 25 watts CFLs can just entered in the parameter.

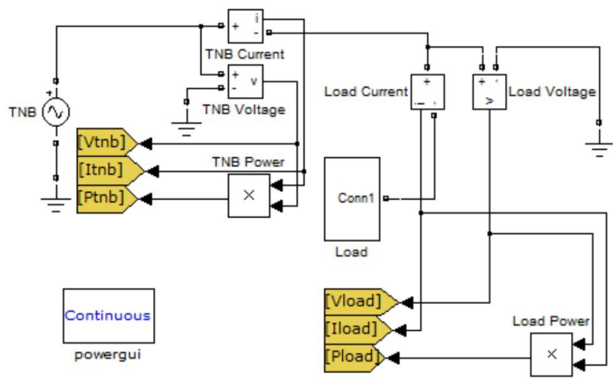

Fig. 8. 240V AC grid system with CFLs simulation diagram

B. Case 2: 240V AC grid system with compact LED lamps

The 240V AC grid system simulates with compact LED lamps as shown in Fig. 9, where LED known as DC driven device. Based on Fig. 9, compact LED lamps operate with AC supply. In order to operate with AC supply, DC driven device should have AC to DC converter as shown in Fig. 10. In MATLAB Simulink, DC device replace with RLC branch while AC device replace with RLC load.

The converter model inside the converter block in Fig. 10 is equivalent with the converter model in Fig. 6.

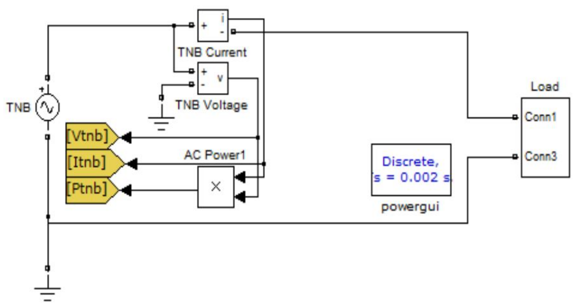

Fig. 9. 240V AC grid system with compact LED lamps simulation diagram

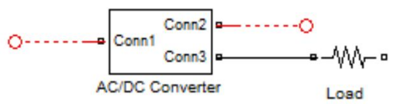

Fig. 10. DC load connected to AC/DC converter

C. Case 3: Proposed system

Simulation diagram for proposed system shows in Fig. 11. That is proposed DC microgrid system with compact LED lamps. It has two supply which are AC supply from utility supply and DC supply from battery. Refers in the figure, there are load block, AC to DC converter block and breaker with timer block. The load model inside the load block is the same with the load model in Fig. 7.

However this simulation consists of 22 parallel connected loads in it. Furthermore, the converter design in Fig. 11 explained in Fig. 6.

The breaker with timer in the simulation functions as switching. It sets for two conditions, when DC supply use AC supply in standby mode and when AC supply use DC supply in standby mode. However, the breaker is not applied in real installation. It just used in simulation for the switching purposes.

The operation of LED with DC supply improved the performance of the system [9]. This study conducts to apply this proposed system at residential and can integrates with solar energy. Energy can be used efficiently as the energy harvest from the renewable energy resources.

IV. Experimental Set up

A. Single line diagram

Experiments are carried out to obtain the real observation data. More data can be collected in the experiments such as power consumption, power factor, operating temperature, luminance and voltage harmonic and current harmonic.

So, it will give clear picture of the comparison between all the cases. Figs. 12, 13 and 14 show the single line diagram of case 1, case 2 and case 3. The figure presents clearly about the differences between all the cases in real situation.

B. Proposed system

Real installation develops after the completion of simulation study. Proposed system wiring diagram shown in Fig. 15. The component that used in real installation may differ in simulation.

For example, in real installation compact LED lamps used as the loads while in simulation it replaced with resistors.

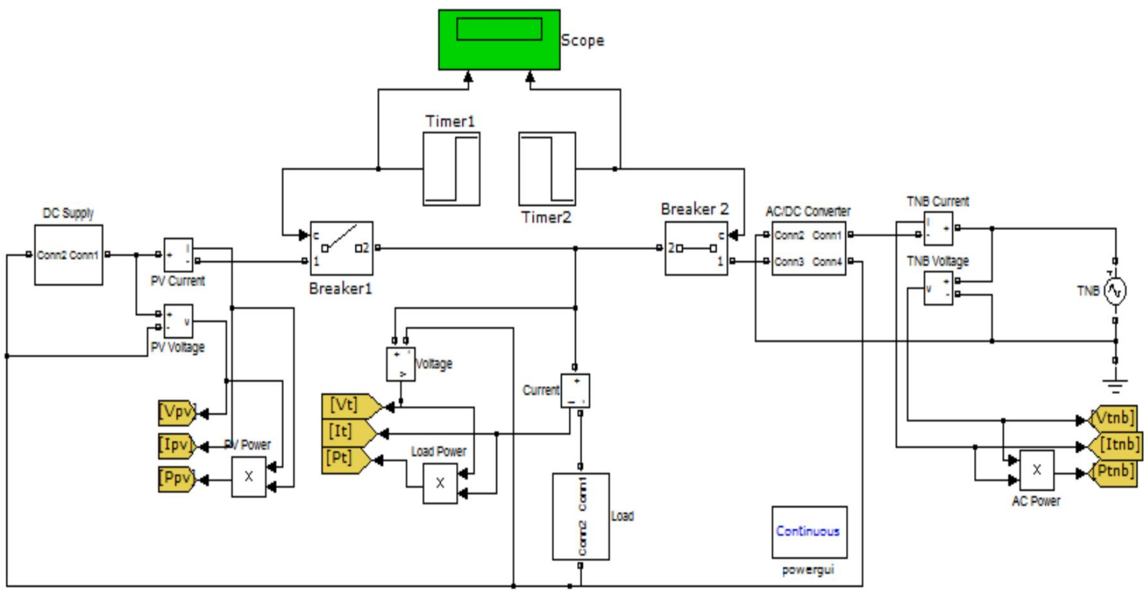

Fig. 11. DC microgrid system with compact LED lamps simulation diagram

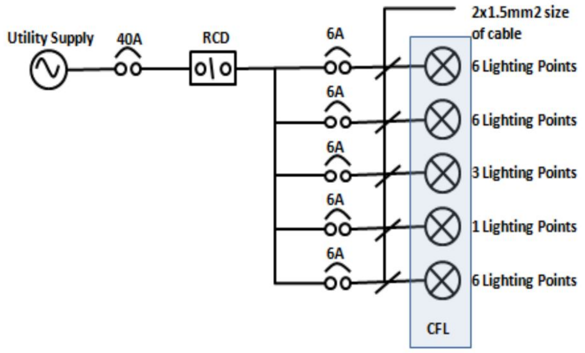

Fig. 12. Case 1 single line diagram

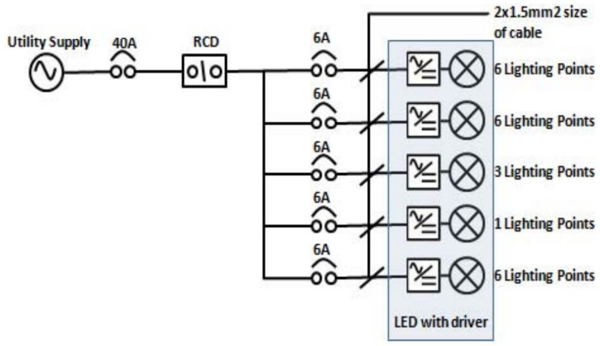

Fig. 13. Case 2 single line diagram

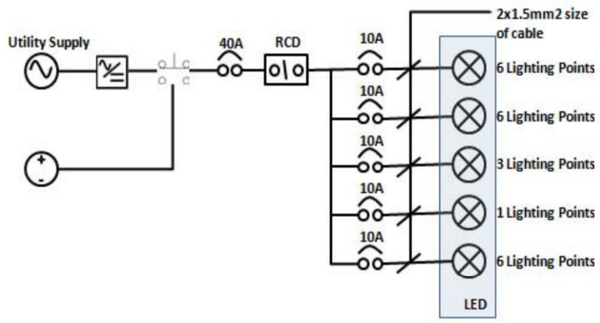

Fig. 14. Case 3 single line diagram

Refers to Fig. 15, there are AC supply, switching mode power supply (SMPS), solar energy, charge controller, battery, contactor, main circuit breaker (MCB), molded case circuit breakers (MCCB) and compact LED lamps. The supply from AC supply connected to SMPS, it used to convert 240V AC to 12V DC. Energy from solar stored in the 12V DC battery.

Contactor in the system functions as the switch. In normal condition, the supply from battery will switch on while AC supply switches off. Protection device applied in this experiment are MCB and MCCB. The standard MCCB rating for lighting are 6A. The maximum number of lamps can be fixed at one 6A MCCB for incandescent, CFL and compact LED lamps shows in Table I.

The calculation for maximum number of lamp fitting example shown below.

At 6A circuit breaker, for 100 watts incandescent lamp:

Current for each load:

$$I = \frac{P}{V} \tag{1}$$

$$I = \frac{100w}{240v}$$

$$I = 0.4167A$$

Maximum number of lamps:

$$N = \frac{6}{0.4167} \tag{2}$$

$$N = 14.4$$

Maximum number of lamp can be installs at 6A circuit breaker are 14 lamps.

TABLE I
NUMBERS OF LAMP FITTING IN ONE CIRCUIT

Supply	Lamp and Wattage	Current, I (Ampere)	Max No. of Lamp Fitting, N
Conventional: 240V AC with 6A MCCB rating	Incandescent (100W)	0.4167	14
	CFL (25W)	0.1875	32
	LED (12W)	0.0900	66
Proposed: 12V DC with 10A MCCB rating	LED (12W)	1.0000	10

Then, the rating for MCB depends on load maximum demand includes the diversity factor of 66% for lighting.

For this experiments, maximum current demand are 50A which are the total current for all MCCB, 66% of 50A are 33A.

The MCB rating that close to 33A is 40A. Then, sizing of cable depends on protection device rating. The size of cable used at 10A MCCB rating is 1.5mm^2. Refers to Table 4D2A in British Standard the suitable size of cable for 10A current rating is 1mm^2.

However, the standard minimum size of cable for lighting is 1.5mm^2. Maximum current can go for 1.5mm^2 cable is 17.5A.

Development of the proposed system conducts at the laboratory. Figure 16 shows all 22 lighting points installed on the ceiling. The data collected based on this installation. Fig. 17 shows all the measurement tool and electronic equipment used in the experiment. There are distribution board, direct current multimeter, lux meter, direct current power supply, switching mode power supply, charge controller and battery.

V. Results

A. Simulation

The circuits are simulates using MATLAB Simulink. The results are taken for full load circuit. Full load circuit indicates the complete lighting circuit for the whole double storey house which consists of 22 lighting points. Table II shows simulation results for all the circuits.

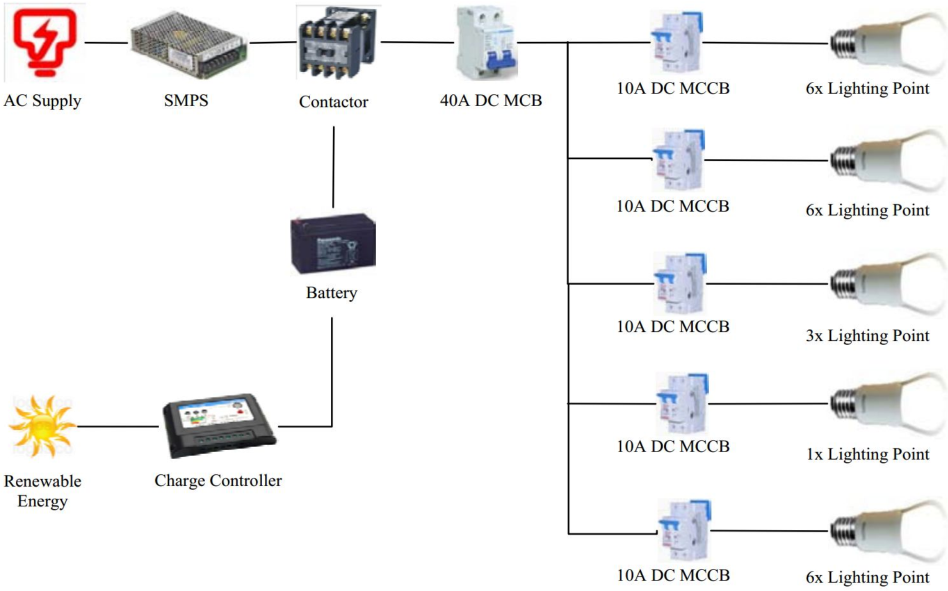

Fig. 15. Proposed circuit wiring diagram

Fig. 16. Lighting points installed on the ceiling

Fig. 17. Electronic equipment and measurement tools

All readings are taken at loads. There are three cases have been simulates, Case 1, Case 2 and Case 3.

Based on the result in the table, most of the cases operate in 240V AC supply except for Case 3 operates in 12V DC.

TABLE II
SIMULATION RESULT DATA

Criteria	Case 1	Case 2	Case 3 DC Supply
Voltage (V)	240	240	12
Current (A)	2.20	1.22	21.29
Power Factor	0.56	0.80	1.00
Power (W)	295.68	234.24	255.48

In term of current consumption, Case 3 with DC supply records highest current value compared with other cases which are 21.29A. The voltage from the utility grid is 240V AC whiles the voltage from DC supply only 12V DC and the value of current vary according to the voltage. However, it consumes only 0.97A at each point. Based on ohm's law, it states that when the voltage decreases the current will increase.

Case 1 uses 25 watts of CFL, while the other cases use 12 watts compact LED lamp. In this case, the 25 watts of CFL has the same number of lumen with 12 watts compact LED lamps. In term of total power consumption, by referring into the table Case 2 consumes the lower power compares to Case 1. This is due to the different type of lamp use in both of the case. However, when compared Case 2 with Case 3, Case 3 has lower power consumption. Even though Case 2 and Case 3 use the same type of lamp, it does not install in the same condition. In Case 2, the compact LED lamps consists LED driver as shown in figure 3, while the compact LED lamps in Case 3 is without the driver as shown in figure 4. Only the supply from utility connects to the AC to DC converter. For Case 3, it has two conditions which are with utility supply and DC supply. The loads that operate in DC supply consume lower power than when it operates using utility supply. This is because when operates with DC supply the loads directly connect to 12V DC supply, while when operates with 240V AC supply it requires an AC to DC converter. As the conclusion, compact LED lamps that operate with DC supply consume lower power than others.

B. Experiments

Experiment results data collect from all the three cases. Based on the data in Table III, the system that operates with DC supply which is Case 3 has won almost all the criteria. However, compact LED lamps run on 12V DC, it has higher value of current compared to others that run with 240V AC.

Rigid development in LED lighting technology will make it as the best lighting in future. In AC system, CFLs in Case 1 compared with the compact LED lamps in Case 2 has proven that compact LED lamps won all the criteria over CFLs. Firstly, compact LED lamps has better power factor compared with CFLs which is 0.8 while CFL has 0.56. Power factor is a measure of the phase of the voltage versus the phase of the current in the system, this phase difference causes higher current flow than would be expected for a given power output, but it does not increase the power consumed. In electrical system, the best power factor is close to unity.

For compact LED lamps, the low power factor might cause by the rectifier in the converter.

Total power consumptions can reduced until 20% when used compact LED lamps that run on AC than CFLs. Furthermore, compact LED lamps operates efficiently with about 0.8 power factor than 0.56 power factor for CFLs. LED may replaced CFLs as energy saving lighting. Total harmonic distortion that taken into consideration in this experiment are total harmonic distortion for voltage (THDv) and current (THDi), refers to Table III, THDv for both CFLs and compact LED lamps considered as low. However, the value of THDi for CFLs is very high which is 85.5% compared to compact LED lamps only 15.5%. The THDi that occurs in LED might be causes by the rectifier that used to convert AC supply to DC supply. It is the same for CFL where rectifier, capacitor and switching transistor is used in the ballast. The AC supply is converted to DC supply using a rectifier then converted back to a high frequency AC supply using the transistor. The low value of THDi is necessary to get a pure sinusoidal wave in AC supply [17]. In term of temperature, LED have smaller value of maximum operating temperature which is 33°C compared to CFL 44°C. The lower the maximum operating temperature is the better because low power requires for the air-conditioning to maintain the desired temperature of the surrounding. It is more reliable in term of economics and power quality effects for the devices with lower heat loss which is lower temperature [18]-[20]. This experiment used the same number of number of lumen for all bulbs which is 1500 and number of pieces for both LED and CFL which is 22 pieces for each type. Nevertheless, in real operation compact LED lamps produce higher luminance than CFLs where there are about 60 lx differs. Although operating in AC, compact LED lamps won all the criteria over CFLs.

In proposed system which refers to Case 3, the compact LED lamps also applied as the load as in Case 2. But, the lamps run on DC system because and the loads operate with DC supply. In this situation, compact LED lamps do not require any converter to operate. The amount of converter used on LED might be reduced. The results shown in Table III shows compact LED lamps that run on DC consumes lower power which is almost 30% from CFLs. Compact LED lamps work efficiently since it has unity power factor, zero in THDv and THDi.

The results obtained from this experiment is consistent with C.K. Gan et. al., Y.K. Cheng et. al. and N.M. Maricar [1]-[22].

TABLE III
PROPOSED SYSTEM EXPERIMENTAL LOAD DATA COMPARED WITH CONVENTIONAL SYSTEM

Parameter	Case 1	Case 2	Case 3
Voltage (V)	240	240	12
Current (A)	2.34	1.32	18.70
Power Factor	0.56	0.8	1.00
Power Consumes (Watt)	314.33	253.44	224.40
Current Harmonic (%)	85.5	15.5	0
Voltage Harmonic (%)	1.2	1.0	0
Operating Temperature (°C)	44	33	33
Lumen	1500	1500	1500
Luminance (lx)	310	370	370

VI. Conclusion

In this paper the proposed system for residential lighting has been simulates and develops to see its performance and it potential to replace the conventional system. Simulation is focus on the load output and effectiveness of inverter. From the simulation result, the proposed system consumes 15% lower energy than the conventional system with CFLs. Refers to experiment result, the proposed system can saves up to 30% energy compared with conventional system with CFLs. The total loads power consumption in simulation for conventional system with CFLs is 295.68 watts, conventional system with LED is 234.24 watts and proposed system is 255.48 watts. However in experiment results, the total loads power consumption for conventional system with CFLs is 314.33 watts, conventional system with LED is 253.44 watts and proposed system is 224.40 watts. On the other hand, this DC microgrid system for residential LED lighting application can be integrated with any renewable energy such as solar and wind.

Acknowledgements

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