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Development of Power Back-Up System using Motor Control for Large Equipment

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***Keywords*— back-up system, engineering, energy, storage devices, uninterruptible power supply.**

***Abstract*— Uninterruptible power supply became a vital technology in the modern era. Through the advancement of technology, the development of this kind of technology seems to be more advanced in terms of size, efficiency, and the delivery of purpose and functionality. However, the compatibility of the device to a certain load remains to be the problem. With this, the researchers developed a power back-up system that can deliver the same purpose for any load including large and critical equipment. This technology was able to vary the storage system capacity, which also integrated the use of other energy sources such as new and renewable. The technology used motor control devices for the same purpose. To validate the effectiveness of the technology, the researchers used factorial design and comparative study to match with the performance of a commercially available uninterruptible power supply. In terms of performance with the commercially available uninterruptible power supply, the comparative study showed that there is no significant difference and thus the power back-up system is as efficient and equally reliable as the commercially available devices. Therefore, the power back-up system is highly adaptable, can substitute commercially available uninterruptible power supply, and can be an effective back-up system for large and critical equipment.*

I. INTRODUCTION

In a developing country like the Philippines, electricity has been a substantial factor in determining economic growth. According to the Asian Development Bank (1), the Philippines has been subjectively experiencing power outage that is approximately 40% and transmission and distribution losses amount to nearly 10% as of 2015, ranking highest amongst Southeast Asian Nations.

An advisable device to compensate for this threat is to consider installing a power back-up system. However, commercially available uninterruptible power supply (UPS) has low back-up power suitable for critical equipment and extortionate (2), has a short lifespan, and is unsustainable. As a solution, the researchers propose a back-up system that is not traditionally made using electronics but instead uses motor control devices. Motor control devices, such as contactors, relays, and time-delay relays, are usually common in an industrial machine. These devices can improve the lifespan of the back-up system device since it is easy to repair, and the device can tailor for any load requirements (3). The power back-up system also can adapt to any power source including renewable energy compared to the commercially available uninterruptible power supply (UPS).

The utmost advantage of the system is the use of a magnetic contactor which eliminates the dependence of the system on electronic components devices (4). Because of this, only the defective components will be replaced and not the whole system. Also, the magnetic contactor acts as a switch and a circuit breaker, therefore, fuse and another delimiting device can be omitted. For the large capacity of equipment, it is advisable to have a heavy-duty system back-up that can withstand the availability of power.

$$i = I_{max} \sin 377t \quad (1)$$

$$v = V_{max} \sin 377t \quad (2)$$

Critical loads have been identified as loads to which power has to be maintained under any circumstances (5). The power supply must not be interrupted as much as possible. Critical loads vary depending on the type of establishment and needs of the company- for instance, an IT infrastructure is the critical load of an IT services company that needs to provide uninterrupted access to its website and online store. For a manufacturing company, a critical load can be equipment whose function is to deliver and process products for the entire day. The power back-up system is a reliable source of continuous power for these critical loads. It is usually integrated into any loads including computers to prevent extemporaneous outage of power. Commercially available uninterruptible power supply (UPS) can be also considered to address the need for continuous power (6). However, limitations of using the UPS system include the short lifespan of the device, impractical operation relative to the time of consumption of power, difficult or impossible repair of malfunctioning parts, and the negative environmental impact of the life cycle of the device. Meanwhile, the power back-up system is proven to be a reliable source of power and is not limited to a specific device. The adaptability of the power back-up system to any equipment will be determined by (1) system performance (2) runtime (3) reliability (4) maintenance and (5) total cost of ownership. The power back-up system can adjust to the requirement of the equipment— capacity and the time it needs to be supplied with pure sine wave power. Composed with motor-control devices, the system can allow replacement of the damaged part without affecting the other components or the whole system, thus, this eliminates the possibility of complete replacement of the equipment and can adapt to any electrical set-up including standby mode. Continuous Power back-up system has been established to be an alternative for commercially available UPS with the advantage as a power back-up system using on-grid supply and renewable energy supply. With the continuous improvement in energy storage technologies, the future of this system is also expected to advance and will be more appreciated in industries.

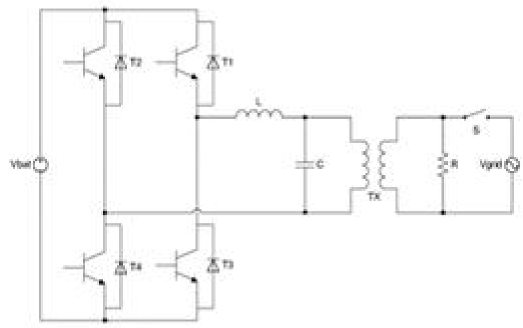

Fig 1. Generic schematic diagram for UPS

The goal of the study is to analyze the developed power back-up system electrical parameters based on the resulting sinusoidal equation requirement of the load (see eq. 1 and 2). The developed power back-up system which uses independent parts integrated to improve maintenance, design, and applicability to large equipment was tested for functionality and reliability using on-grid supply and renewable supply.

II. REVIEW OF RELATED LITERATURE

Electricity storage can be deployed throughout an electric power system. A UPS is an example of an electricity storage application. Commercially available UPS has been a vital part of the power system of the commercial establishment for the prevention of sudden shut-off (7). The disadvantages of using UPS include difficulty in repairing electronic parts that are embedded in the printed circuit board. (See schematic diagram above) (8).

For the development of the Back-up System, electronic components are being omitted and replaced by fewer maintenance devices such as contactors and relays. The power back-up system is also adjustable to the power sources including renewable energy.

Motor control devices are used to regulate the operation of an electrical motor in prescribed settings. Motor controls are also known as motor controllers. Some of the functions include automatic start and stop of the operation of the electric motor, forwarding or reversing the course of rotation, regulation of rotor speed, and adjusting the torque setting (9). These devices protect the electrical motor from overloads and faults. Moreover, these devices can be applied to other applications including non-motor loads for purposes indicated as advantages of motor control devices (10).

There are different types of motor control devices (11). These include motor control starters, motor circuit breakers, contactors, mini contactors, thermal overload relays, and time-delay relay. Each of these is different in function and can be used to functionality control the performance of a motor. In the setup indicated in the project, the researcher will only use a motor circuit breaker, time delay relay, and contactor.

Magnetic control permits the installation of power contact close to the load (12). It also provides safety features, which limit the use of fuse and other delimiting devices. The magnetic control device also has switching controls, which make the system independent in terms of per unit assembly. Each device will make the system safe and take replacement of devices easily. Also, since it is a power back-up system, the magnetic contactor acts as a balancer that homogenizes changes in electrical frequency. Once abnormalities are detected in the electrical supply, the contactor will switch the electrical supply source.

III. METHODOOLOGY

The researchers will follow the simple protocol for prototype designing. A prototype is an early sample, model, or release of a product built to test a concept or process. It is a term used in a variety of contexts, including semantics, design, electronics, and software programming. First, the researchers constructed a material architecture based on the concept of using motor control devices such as contactors, timer relay, and power relay. The researcher also uses simulation software to further develop the schematic diagram.

The researchers developed the prototype, designed accordingly to the analysis result of the simulation. The system was further evaluated with several testing before proceeding with commissioning.

The researcher analyzed the combinational effect of the factors using a factorial design. Instead of conducting a series of independent studies, the researchers were effectively able to combine these studies.

The study included comparative research, to analyze the research problem. Using the parameters of power in watts, samples are treated using a match paired t-test. Comparative research seeks to decipher the relationship between two or more parameters by obtaining observed similarities and differences between two or more subjects or groups (13).

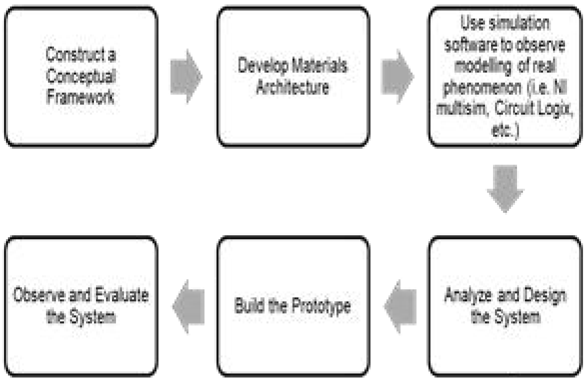

Fig 2. Prototype Model Methodology

IV. RESULTS AND DISCUSSION

The researcher conducted a statistical analysis in terms of the line voltage supply to the load by the utility mode and the back-up mode.

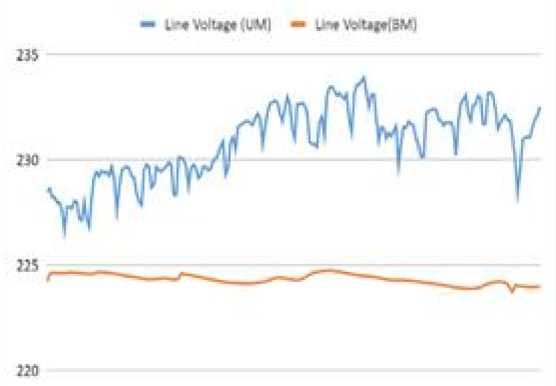

Fig 3. Comparative graph of the line voltage of the System in Utility Model and in Back-up Mode using the datalogger

Figure 3 shows the line voltage input from the system using the utility mode and the back-up mode. As shown, the line voltage of the Back-up system is more stable than the line voltage in Utility mode. But both voltages are within the voltage variation level of +/-10% of the rated voltage (standard based on the Phil Distribution Code and U.S. National Electric Manufacturers Association or NEMA).

From the result using match paired t-test, the data shows that the t-critical two-tailed is lesser than the statistical t-result (1.972<50.77). This shows that there is no significant difference in the data of line voltage for utility mode and back-up mode thus accepting the null hypothesis. In terms of correlation, the data shows that there is a mid-level significance with movement of the utility-mode line voltage versus the back-up mode line voltage (Refer to Table 1).

Table 1. t-Test: Paired Two Sample for Means for Line Voltage

	Utility Mode	Back-up Mode
Mean	230.8411	224.3502
Variance	2.932314362	0.056652221
Observations	200	200
Pearson Correlation	-0.343586871	
Hypothesized Mean Difference	0	
df	199	
t Stat	50.77026603	
P(T<=t) one-tail	3.7404E-116	
t Critical one-tail	1.652546746	
P(T<=t) two-tail	7.4808E-116	
t Critical two-tail	1.971956544	

Table 2. t-Test: Paired Two Sample for Means for Line Current

	Utility Mode	Back-up Mode
Mean	0.4125895	0.435033
Variance	1.47231E-05	9.25539E-07
Observations	200	200
Pearson Correlation	-0.497103236	
Hypothesized Mean Difference	0s	
df	199	
t Stat	-72.21329874	
P(T<=t) one-tail	5.1489E-145	
t Critical one-tail	1.652546746	
P(T<=t) two-tail	1.0298E-144	
t Critical two-tail	1.971956544	

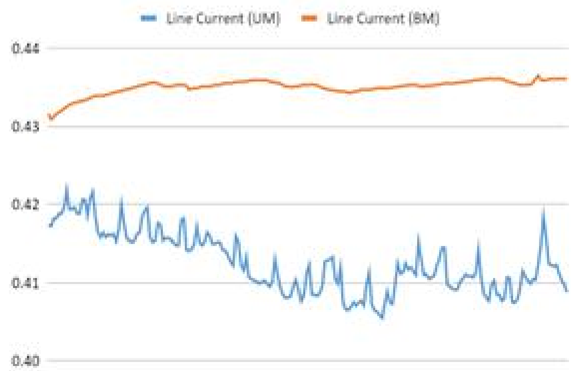

Fig 4. Comparative graph of the line current of the System in Utility Model and in Back-up Mode using the datalogger

The researcher conducted a statistical analysis in terms of the line current supply to the load by the utility mode and the back-up mode. Figure 4 shows the line current of the system using the utility mode and the back-up mode. As shown, the line current supply of the Back-up system is stable, while the line current in Utility mode is fluctuating.

From the result using match paired t-test, the data shows that the tcritical two-tailed is lesser than the statistical t-result (1.972<72.21). This shows that there is no significant difference in the data of line current for utility mode and back-up mode, thus accepting the null hypothesis. In terms of correlation, the data shows that there is a mid-level significance with movement of the utility-mode line current versus the back-up mode line current (Refer to Table 2).

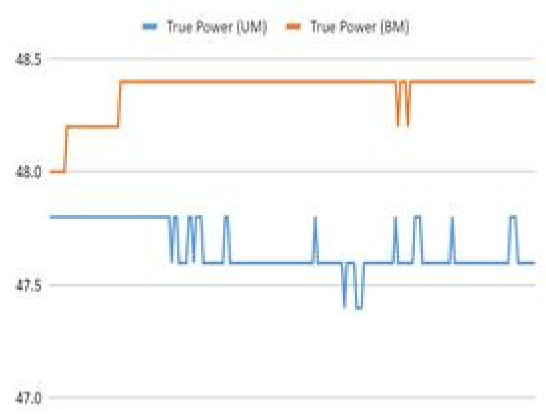

Fig 5. Comparative graph of the true power of the System in Utility Model and in Back-up Mode using the datalogger

The researcher conducted a statistical analysis in terms of power in watts between utility mode and the back-up mode to determine the reliability of supply from different modes. Figure 5 shows the true power of the system using the utility mode and the back-up mode. As shown, the true power output of the Back-up system is higher than in Utility mode. This shows that there is higher actual power generated by the equipment to do useful work.

From the result using match paired t-test, the data shows that the tcritical two-tailed is lesser than the statistical t-result (1.972<58.02). This shows that there is no significant difference in the data of power in watts for utility mode and back-up mode thus accepting the null hypothesis. In terms of correlation, the data shows that there is a mid-level significance with movement of the utility-mode power versus the back-up power. (Refer to Table 3)

Table 3. t-Test: Paired Two Sample for Means for True Power

	Utility Mode	Back-up Mode
Mean	47.664	48.362
Variance	0.010355779	0.009001005
Observations	200	200
Pearson Correlation	-0.496336575	
Hypothesized Mean Difference	0	
df	199	
t Stat	-58.02509743	
P(T<=t) one-tail	5.7304E-127	
t Critical one-tail	1.652546746	
P(T<=t) two-tail	1.1461E-126	
t Critical two-tail	1.971956544	

Fig 6. Comparative graph of the power factor of the System in Utility Model and in Back-up Mode using the datalogger

The researcher conducted a statistical analysis in terms of the power factor between utility mode and the back-up mode.

Figure 6 shows the true power of the system using the utility mode and the back-up mode. As shown, the power factor of the system for both back-up and utility mode is almost 0. This shows that the energy flow is entirely reactive and the stored energy in the load returns to the source on each cycle.

From the result using match paired t-test, the data shows that the tcritical two-tailed is lesser than the statistical t-result (1.972<98.36). This shows that there is no significant difference in the data of power factor for utility mode and back-up mode thus accepting the null hypothesis. In terms of correlation, the data shows that there is a low-level significance with movement of the utility-mode power factor versus the back-up power factor. (Refer to Table 4)

Table 4. t-Test: Paired Two Sample for Means for Power Factor

	Utility Mode	Back-up Mode
Mean	-0.004751	-0.0037415
Variance	1.17578E-08	7.16357E-09
Observations	200	200
Pearson Correlation	-0.116791237	
Hypothesized Mean Difference	0	
df	199	
t Stat	-98.36482245	
P(T<=t) one-tail	5.4492E-171	
t Critical one-tail	1.652546746	
P(T<=t) two-tail	1.0898E-170	
t Critical two-tail	1.971956544	

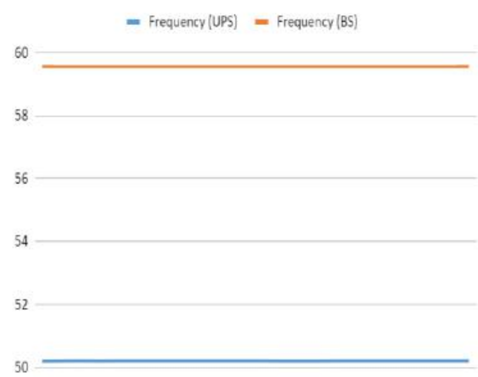

Fig 7. Comparative graph of the frequency output of the back-up system vs the commercially- available Uninterruptible Power Supply (UPS)

The researcher conducted a comparative study of electrical performance between the developed power back-up system technology versus the commercially available UPS in terms of frequency. Figure 7 shows the comparative study of the frequency output of the back-up system vs the commercially- available Uninterruptible Power Supply (UPS). The frequency operating in the Philippines shall be 60 Hz, with the allowable variation of 59.7 to 60.3 Hz. The graph shows that the back-up system is within the allowable variation whereas the commercially available UPS is only at about 50Hz.

From the result using match paired t-test, the data shows that the tcritical two-tailed is lesser than the statistical t-result (2.05<19346.81). This shows that there is no significant difference in the data thus accepting the null hypothesis. This shows that the performance of the developed power back-up system is comparable with the commercially available UPS in terms of frequency. (Refer to Table 5)

Table 5. t-Test: Paired Two Sample for Means for Frequency

	Uniterrupted Power Supply	**Back-up System**
Mean	50.19286667	59.549
Variance	7.01609E-06	2.08912E-28
Observations	30	30
Pearson Correlation	0	
Hypothesized Mean Difference	0	
df	29	
t Stat	-19346.81119	
P(T<=t) one-tail	5.742E-105	
t Critical one-tail	1.699127027	
P(T<=t) two-tail	1.1484E-104	
t Critical two-tail	2.045229642	

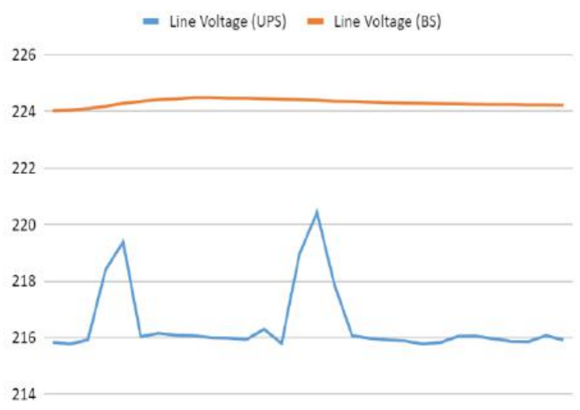

Fig 8. Comparative graphs of the line voltage of the back-up system vs the commercially- available Uninterruptible Power Supply (UPS)

The researcher conducted a comparative study of electrical performance between the developed power back-up system technology versus the commercially available UPS in terms of line voltage. Figure 8 shows the comparative study of the line voltage output of the back-up system vs the commercially- available Uninterruptible Power Supply (UPS). As shown, the line voltage of the developed back-up system is more stable than the line voltage of the UPS. But both voltages are within the voltage variation level of +/-10% of the rated voltage (standard based on the Phil Distribution Code and U.S. National Electric Manufacturers Association or NEMA).

From the result using match paired t-test, the data shows that the tcritical two-tailed is lesser than the statistical t-result (2.05<35.63). This shows that there is no significant difference in the data thus accepting the null hypothesis. This shows that the performance of the developed power back-up system is comparable with the commercially available UPS in terms of line voltage. (Refer to Table 6)

Table 6. t-Test: Paired Two Sample for Means For Line Voltage

	Uniterrupted Power Supply	**Back-up System**
Mean	216.475	224.3096667
Variance	1.471743103	0.01561023
Observations	30	30
Pearson Correlation	0.12183761	
Hypothesized Mean Difference	0	
df	29	
t Stat	-35.6315269	
P(T<=t) one-tail	8.50947E-26	
t Critical one-tail	1.699127027	
P(T<=t) two-tail	1.70189E-25	
t Critical two-tail	2.045229642	

Table 7. t-Test: Paired Two Sample for Means For Line Current

	Uniterrupted Power Supply	**Back-up System**
Mean	0.53424	0.435076667
Variance	5.75459E-05	1.34954E-07
Observations	30	30
Pearson Correlation	0.076321367	

Hypothesized Mean Difference	0
df	29
t Stat	71.77994425
P(T<=t) one-tail	1.63096E-34
t Critical one-tail	1.699127027
P(T<=t) two-tail	3.26192E-34
t Critical two-tail	2.045229642

The researcher conducted a comparative study of electrical performance between the developed power back-up system technology versus the commercially available UPS in terms of line current. Figure 9 shows the comparative study of the line current output of the back-up system vs the commercially- available Uninterruptible Power Supply (UPS). As shown, the line current of the developed back-up system is more stable than the line current of the UPS.

From the result using match paired t-test, the data shows that the tcritical two-tailed is lesser than the statistical t-result (2.05<71.77). This shows that there is no significant difference in the data thus accepting the null hypothesis. This shows that the performance of the developed power back-up system is comparable with the commercially available UPS in terms of line current. (Refer to Table 7)

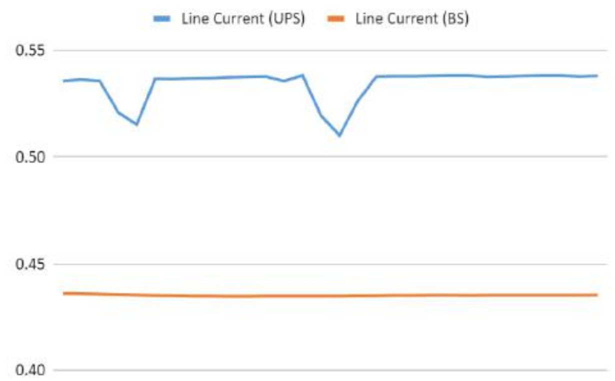

Fig 9. Comparative graphs of the line current of the back-up system vs the commercially- available Uninterruptible Power Supply (UPS)

Table 8. t-Test: Paired Two Sample for Means for True Power

	Uniterrupted Power Supply	Back-up System
Mean	59.72666667	48.28
Variance	0.335126437	0.009931034
Observations	30	30
Pearson Correlation	-0.062163256	
Hypothesized Mean Difference	0	
df	29	
t Stat	105.639555	
P(T<=t) one-tail	2.31181E-39	
t Critical one-tail	1.699127027	
P(T<=t) two-tail	4.62363E-39	
t Critical two-tail	2.045229642	

Figure 10 shows the comparative study of the true power of the back-up system vs the commercially- available Uninterruptible Power Supply (UPS). As shown, the true power output of the developed back-up system is lower than the UPS. To verify the significance of the difference. A paired two-sample t-test was conducted by the researchers. The researcher conducted a comparative study of electrical performance between the developed power back-up system technology versus the commercially available UPS in terms of line true power.

From the result using match paired t-test, the data shows that the tcritical two-tailed is lesser than the statistical t-result (2.05<105.64). This shows that there is no significant difference in the data thus accepting the null hypothesis. This shows that the performance of the developed power back-up system is comparable with the commercially available UPS in terms of power (watts). (Refer to Table 8)

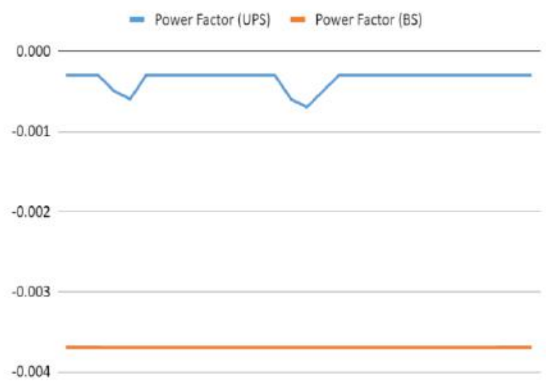

Fig 11. Comparative graph of the power factor of the back-up system vs. the commercially- available Uninterruptible Power Supply (UPS)

The researcher conducted a comparative study of electrical performance between the developed power back-up system technology versus the commercially available UPS in terms of line power factor. Figure 11 shows the

Table 9. t-Test: Paired Two Sample for Means for Power Factor

	Uniterrupted Power Supply	**Back-up System**
Mean	-0.000346667	-0.0037
Variance	1.22299E-08	1.75108E-36
Observations	30	30
Pearson Correlation	2.21589E-16	
Hypothesized Mean Difference	0	
df	29	
t Stat	166.0833766	
P(T<=t) one-tail	4.73017E-45	
t Critical one-tail	1.699127027	
P(T<=t) two-tail	9.46033E-45	
t Critical two-tail	2.045229642	

comparative study of the power factor of the back-up system vs the commercially- available Uninterruptible Power Supply (UPS). As shown, the power factor of the developed back-up system is lower than the UPS. To verify the significance of the difference. A paired two-sample t-test was conducted by the researchers.

From the result using match paired t-test, the data shows that the tcritical two-tailed is lesser than the statistical t-result (2.05<166.08). This shows that there is no significant difference in the data thus accepting the null hypothesis. This shows that the performance of the developed power back-up system is comparable with the commercially available UPS in terms of power factor. (Refer to Table 9)

V. CONCLUSION

The power back-up system replaces commercially available UPS to address issues that are for the advantage of the developed backed-up system. Inclusions that are part of the objectives are: simplicity yet sturdy design, easy operation, and maintenance, use of locally-available materials for fabrication.

Solution for the need of a continuous source of energy without interruption for large equipment. For comparative study in terms of scalability, input voltage, output voltage, input current, and output current tend to have no significant difference between utility mode and back-up mode. This shows that the performance of the delivered electrical parameter using two different supplies has no variations when using the power back-up system. There is also evidence that the parameters indicated in the experimental design are highly significant and tend to affect the performance of the power back-up system. The researchers also indicated the importance of the performance of the parameters for both utility mode and back-up mode for the technology. The effect of the voltage, current, power, and power factor are compared using a comparative study. The data portray evidence that there is no significant difference in the performance in terms of the electrical parameters supply in the load for the power back-up system. Therefore, it is concluded that the power back-up system is highly adaptable and can be a substitute technology for commercially available uninterruptible power supply and can be a technology that will provide a back-up system for large equipment.

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