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Review Article

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A Comparative Study Between Single Phase Rectifier and Three Phase Rectifier: Running the Inverter Technology Operated Home Appliances

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Abstract

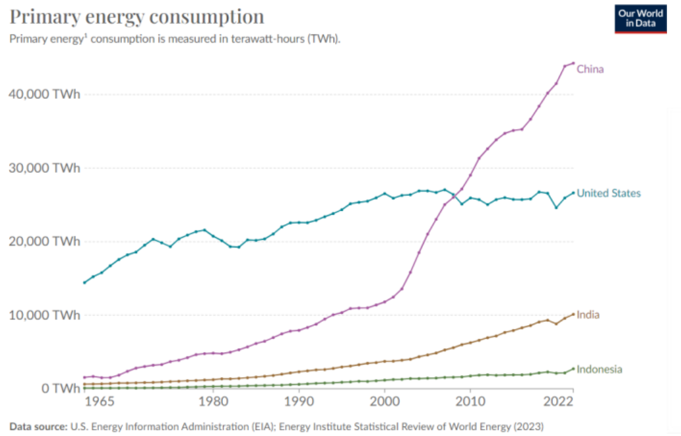
Domestic appliances nowadays are equipped with inverter technology that reduces energy consumption and lowers the bill users are charged with. Modern homes are loaded with electrical appliances that are an essential part of daily life. The higher number of appliances needs high power. Appliances with an inverter technology make use of single-phase rectifier circuits. A simply designed three-phase rectifier circuit can produce a higher value of DC level than a single-phase rectifier circuit. The paper discussed a comparative study between two simple rectifier schemes and used simulation to show the better performance of three-phase circuits while delivering high power to loads. The loads considered in this study are domestic loads where load fluctuation almost does not occur. Complex control schemes along the rectifier arrangement were also eliminated to simplify the approach. The discussion concludes the acceptable and satisfactory outcome at a low cost and with ease in all aspects of designing, installation, maintenance and sustenance.

1. Introduction

The graph of novel technical solutions is on the rise forever. The ever-increasing need and interest be streamlined by the rise of population, the demand of the mass people in different scenarios, the limited resources within nature, careful optimization of the resources reducing exploitation and harmful spinoffs, ensuring the sustainability of civilization and such other elaborations.

The trending technologies-from automations to artificial intelligence, from block chain to IoT, from big data analysis to industrial revolutions-are bound by the necessity of using electrical power. Vast aspects are taken into consideration while dealing with electrical power. The generation of power considers consumptions of existing limited, traditional and natural resources. The last decade, though, saw the renewable energy trend associated with solar, wind and biofuel energy systems. The transmission system between the generation and the distribution side is a considerable side while scheming the cost of electrical power engagement. Lastly comes the necessity of efficiency in feeding and reciprocating energy at the load side. This is where the cost and the consumer stand right next to each other. The manufacturers are actively and endlessly working on inventing and promoting designs that are efficient in terms of cost, maintenance, installation and long-term use to satisfy the end users.

The escalating trend [1,2] in energy consumption is obvious when it is documented against the population of the countries [3]. The rising demand can be backed up by efficient schemes that will power maximum electrical load using the minimum resources. The greater percentage of electrical power consumption [4,5] in today's world is by the industrial sectors followed by residential load as the second largest consumer.



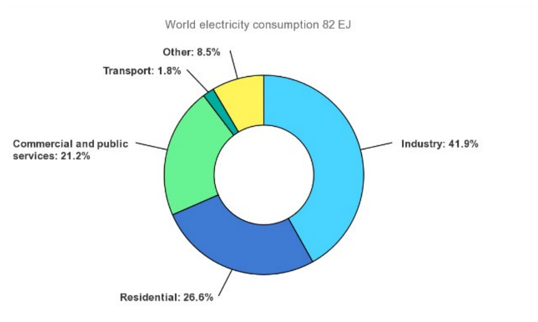


Figure 1: (a) Energy Consumption by Countries [2], (b) Energy Consumption by Sectors [5].

Domestic users are dependent on technologies and have an open door for electrical goods. The growing demand for electrical energy in day-to-day life is paving the way to look for smart solutions. Comparisons study different types of electrical machines looking for less equipment and simpler connections to curb the need.

The AC machines occupy a significant part of the electrical network. AC motors are more powerful and come with the benefit of minimized transient current. DC motors on the other hand, have cost effective installation and maintenance along with quicker response time [6,7]. The multi-level voltage regulation of DC motors does not need complexly designed controllers therefore becomes cost effective and easy to maintain. [6,8]. Though DC motors are many times preferred over AC motors, AC clearly leads by the advantages while transmitting over long distances over DC [6,9]. Inverter technology in modern-day home appliances gets the best of combining the former mentioned pros of AC transmission and DC motor control.

The commercially known inverter technology needs stable, ripple-free DC voltage input. That DC voltage is obtained from rectifier circuits that is fed by a 1-Φ AC. The main function of the arrangement is to provide various drive systems in electrical appliances with optimum amounts of energy. The inverter technology enables savings of energy and aids in the conservation of energy. It enables finer operation of electromechanical circuitry within the equipment compared to that of former non-inverter appliances and provides users with a better experience while cutting down on the cost in the extended time of use [10-12].

2. Literature Review

The background study primarily focused on the procurement of DC output from either a 1-Φ or a 3-Φ rectifier circuit. A 3-Φ inverter is more suited for driving loads at high voltage and high power. The comparative studies and research work include obtaining a constant DC voltage level from a 3-Φ rectifier circuit [13] to incorporate various schemes with switched 3-Φ to eliminate the harmonics and improve other aspects of it. [14-18].

Later the study revolved around research works of contemporary times. These included different types of control systems [19-20] for inverters combining different logics, various algorithms, and cascading in-effect technologies for the best possible performances. The majority of the functioning inverter appliances work on the principle of obtaining DC from 1-Φ DC. Though some works [21] suggested deriving DC from e 3-Φ supply, the output obtained was not suited to run motors having ratings of higher voltage and current.

The demand for DC motors and the demand of high-power motors, as shown in the graphs of figure 2 [16] is growing rapidly in domestic and industrial applications for their swift operation and capability to perform in a perplexing environment [16,17]. Since high-power motor operation is becoming trendy, the DC output obtained from a 1-Φ AC input seems to be becoming less suitable.

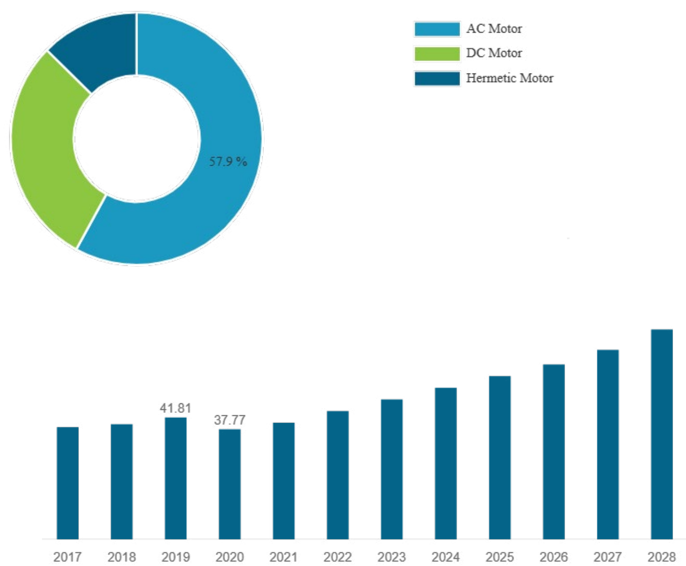


Figure 2: (a) Global Electric Motor Market Share, by Motor Type (2020), (b) Asia Pacific Electric Motor Market Size in USD Billion (2017-2018)

3. Topology

The output of a rectifier circuit is fed to the load circuit. Intermediate boosters and reactive elements are used to improve the voltage stability. The quality of the output can be enhanced greatly by utilizing various methods. But in this study, the circuit was kept fundamental and straightforward.

The basic approach to process the output of the rectifier to handle higher loads is to add capacitors and inductors to eliminate the distortion that occurs at high power. Obtaining a satisfactory voltage at the output of a 1-Φ rectifier needs L and C elements. That too, is of significant value and multiple in most cases. This addition makes the circuit complex and bulky. Voltage of a similar quality can be obtained from a 3-Φ rectifier without the additional components that saves on the volume and weight of the existing circuit. The coupling of the capacitor-inductor at the output of a 3-Φ rectifier yields far better results when similar connectivity of the same valued capacitor-inductor is used at the output of a 1-Φ rectifier circuit. A 3-Φ rectifier circuit can work with a lower-valued capacitor-inductor to obtain a satisfactory result.

The final output voltage state in case of high power (i.e. higher load in practical case) can be assessed by adding a booster at the output and tracing the follow-on voltage. The amount of undulations present at the higher level of voltage output can conclude the performance of the proposed setup. The obtained DC voltage can be used to drive a higher number of inverters to run appliances or load of high power altogether.

4. System Arrangement

To design a 3-Φ rectifier circuit, the foremost consideration is to bring 3-Φ power up until the rectifier circuit. The major parameter, copper cost, of such an arrangement in comparison with that of a 1-Φ is lesser. For 1-Φ, $P=VI\cos\theta$ and for 3-Φ, $P=\sqrt{3}V_LI_L\cos\theta$; Therefore, the copper needed for specific power and power factor is always smaller in amount in case of a 3-Φ arrangement than the copper needed in a 1-Φ arrangement.

The proposal engages and studies the simple construction of a 3-Φ rectifier circuit. The switching methods of such arrangements are not incorporated. So harmonic distortion is well-thought-out to be zero. The objective circled around the attaining of greater value of DC average with minimal distortion.

The inverter circuit in home appliances utilizes a booster circuit to obtain the necessary DC voltage and power for the driver circuit. An IGBT along with the switching arrangements represents the booster arrangement for the output of the rectifier circuits. The same model is integrated in both 1-Φ and 3-Φ schematic. This addition analyzes the performance of typical arrangements while providing power to large amounts of electrical load. The circuit arrangement in figure: 5 (a) shows a 3-Φ rectifier circuit. The output of the rectifier is boosted to supply a load of 50Ω. The load receives about 12kW (pf=1) at 800V. The graph in figure: 5 (b) shows the output voltage.

The capacitors and inductors are added in the 3-Φ schematic in an attempt to stabilize the output after the boost. A similar arrangement is used along the 1-Φ rectifier with a booster arrangement. Both arrangements are studied while powering the load of the same rating. The arrangements are shown in figure: 4 (a) (1-Φ) and figure: 6 (3-Φ). The outputs of the rectifier circuits are shown in the graph in figure: 4 (b) and in figure: 7. The comparison obtained from the visual findings of the graphs is discussed in the next section.

5. Simulation

The schematic in figure: 3(a) is a basic 1-Φ rectifier circuit. The set-up can maintain a stable output while powering a load at low voltage and of low power but that too with the help of capacitors and inductors of fairly enough large value (100uF in parallel, 100mH in series). The output i.e. voltage and power across the load is shown in the graph of figure: 3(b). The output maximum voltage after the transient is 1kV and very stable. The supplied power is averaged around 250W. The 1-Φ rectifier arrangement in figure: 4(a) obtains the output voltage as shown in figure 4(b) when fed through a booster. The graphical result indicates that the voltage (PR3) struggles to keep a stable amplitude compared to the plain output from the rectifier (PR2) before boosting.

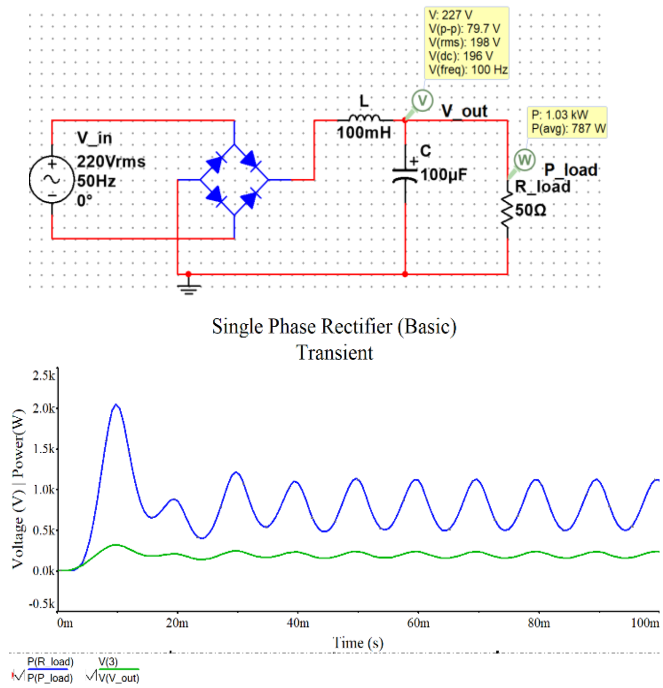


Figure 3: (a) Schematic of a Basic 1-Φ Rectifier Circuit, (b) Output Voltage and Power of the Arrangement when Supplying an Approximate 700W (Average) Load

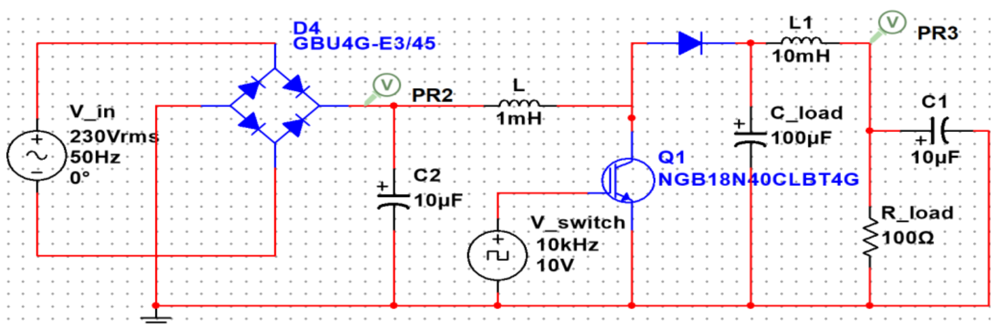


Figure 4: (a) Schematic of a Basic 1-Φ Rectifier Circuit with Booster and Filtering Elements

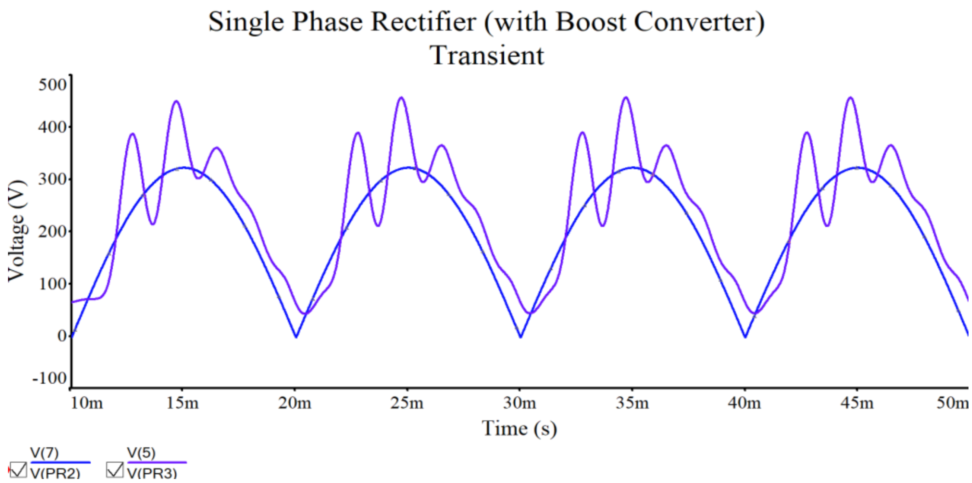


Figure 4: (b) Output Voltage of the 1-Φ Rectifier Circuit (PR2) Compared to the Output of the Circuit While Supplying an Approximate 1.1kW Load (PR3)

The schematic in figure: 5(a) is a basic 3-Φ rectifier circuit. The setup can maintain a stable output while powering a load at low voltage and of low power. Though a capacitor is used at the output across the load to keep the comparison straightforward with the setup and result of the 1-Φ rectifier circuit. The output i.e. voltage and power across the load is shown in the graph of figure: 5(b). The output maximum voltage after the transient is 2kV and very stable. The supplied power is averaged around 250W.

The arrangement in figure: 6 is a 3-Φ rectifier circuit connected with booster and filtering elements. Figure 7(a), 7(b) show the output voltage of the 3-Φ rectifier circuit when fed through a booster. The graphical result indicates the obvious high output voltage (PR1) obtained a maximum of 800V. Though there is a little instability at output voltage (PR2), the variation falls in the range of 790V to 800V.

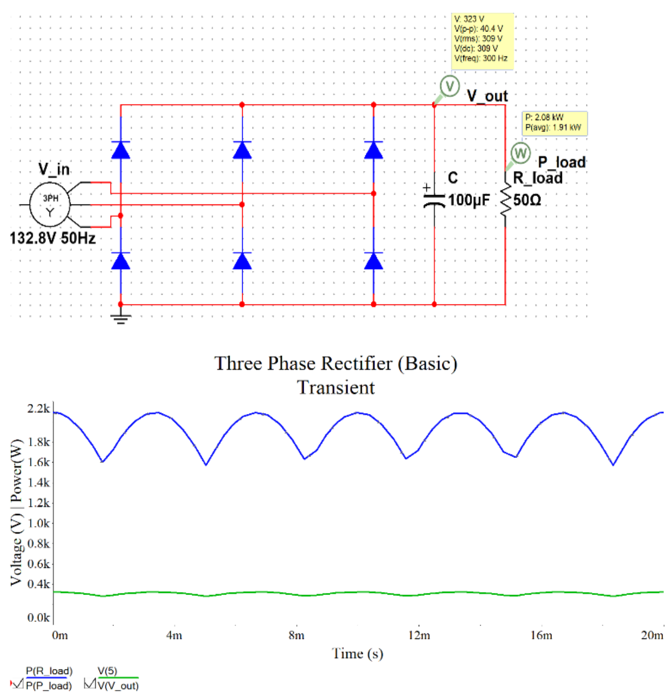


Figure 5: (a) Schematic of a Basic 3-Φ Rectifier Circuit, (b) Output Voltage and Power of the Arrangement when Supplying an Approximate 2kW Load

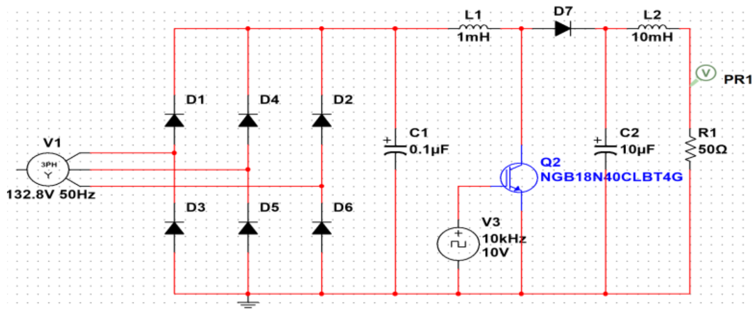


Figure 6: Schematic of a Basic 3-Φ Rectifier Circuit with Booster and Filtering Elements

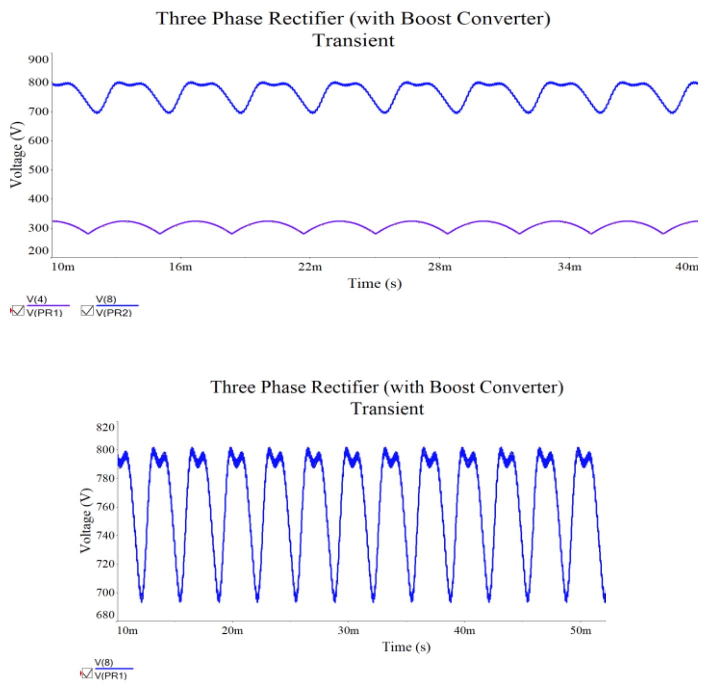


Figure 7: (a) Output Voltage of the 3-Φ Rectifier Circuit (PR1) Compared to the Output of the Circuit after Boosting and Supplying an 11.5kW load (PR2), (b) Output Voltage of the 3-Φ Rectifier Circuit After Boosting (PR1)

6. Results

The output from the 1-Φ rectifier circuit when connected to the booster circuit barely maintains the voltage level. Improvement in generated power is not very significant as well. The schematic in figure: 4 (a) shows a number of filtering elements (10uF capacitor in parallel, 1mH inductor in series; after boosting, 100uF capacitor in parallel, 10mH inductor in series, 10uF capacitor in parallel). These elements enhance the size of the appliances making the installation and maintenance difficult and costly. Also, the DC level (Vrms = 230V per phase, so across the line i.e. load) obtained is not that sufficient to run equipment at high voltage and high power (1kW~1.5kW).

As can be seen from figure: 4 (b), the output voltage of the 1-Φ rectifier is crowded with ripples after the addition of a booster circuit to feed a load of around 1kW. The ripples further increase if the boosting is done to supply higher values of load. It becomes difficult to maintain a steady output at the rectifier, even with several filtering elements.

On the other hand, the output from the 3-Φ rectifier circuit when connected to the booster circuit can maintain the voltage level. As can be seen from the schematic in figure: 6, some filtering elements (0.1uF capacitor in parallel, 1mH inductor in series; after boosting, 10uF capacitor in parallel, 10mH inductor in series). The number of such filtering elements required to obtain satisfactory results is fewer, the values are also smaller. The DC level (Vrms = 132.8V per phase, 230V across the line i.e. load) obtained is sufficient to run equipment at high voltage and high power (~10kW).

As can be seen from figure: 7 (a) and figure: 7 (b), the ripples present at the output of the 3-Φ rectifier circuit are low when compared as a percentage of the obtained voltage. Subjecting the circuit to further boosting, does not increase ripples to the extent as it does in the case of a 1-Φ rectifier circuit.

The typical case of connecting boost converters after the rectification process is discussed in this study as it can feed a load of the same power but with double voltage. The integration is highly sensitive to loads connected. In single phase, connecting booster degrades the quality of output voltage and can somewhat be unfeasible. With the three-phase system, the booster works in favor. It can feed roughly five times the load directly or with a booster to raise the voltage to double.

7. Proposed Schemes

Effortlessly produced DC value for feeding at the input of the inverter circuit can be used to design and implement smart homes more dynamically. The inverter technology can be integrated into other home appliances apart from the existing ones while keeping pace with the growing demand. The production of voltage and power at a low cost and simple design can be used to support the increasing load. It can also encourage adaption to the digitalization of domestic life while optimizing the available energy and reducing wastage. The rise in demand of DC supply for equipment can instigate the design of a better feeding system; For example, a common DC bus installed locally at home for greater efficiency. Many appliances use the DC voltage as input to 3-Φ inverters. The inverter can drive, for example, BLDC motors of a few kW. Thus, the effectiveness of the 3-Φ system with a higher level of output voltage is to the mark. The dc-to-dc converter, a more efficient electrical-to-electrical energy converter, can be used more frequently and in more quantity. For home appliance having a few levels of DC voltages, can be operated by generating multilevel voltages using several DC-to-DC converters.

Options to lead the system with three-phase inverters will encourage the home appliance designer to use a three-phase motor as its speed and torque can be controlled more efficiently. Charging vehicles' batteries will be a regular feature of modern life. The charger would be simpler; hence less maintenance will be required. And the charger can handle more power needed to charge the battery.

8. Conclusion

Advancing in technology not only means inventing, designing and implementing newer methods for the greater good and better outcomes but also being economical to avoid wasting energy and to not create negative impact. There are disadvantages of using higher rating bulk sized electrical machineries over using smaller units in plain view. But filtering components like the electrolytic capacitors or inductors would be of less value and hence much smaller in size to accommodate in the PCB unit when a 3-Φ rectifier is integrated into the system. As mentioned earlier, such a scheme also eliminates the additional requirement in copper use while wiring and minimizes the cost.

The study put the usefulness of using a 3-Φ power system for household power distribution system instead of a 1-Φ supply. The study emphasized the utility of a 3-Φ rectifier in the appliances with inverters. The discussion highlighted the simplicity of design followed by ease of combination and cost-effectiveness. The implementation of such a simple system can be developed on focusing the designing of more powerful and efficient equipment.

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