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Integrating Solar-Powered PV Cells And SCR-Controlled Three-Phase Rectifiers to Design A Two-Level DC Grid Architecture

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ABSTRACT: The use of electrical equipment is booming with the growth of the population and the advancement of technology. Acceptance largely depends on cost-benefit considerations during production, distribution, and use. Power electronics, especially inverter and buck-boost converter technology, perfectly serves the purpose nowadays. Equipment embedded with this technology has gained popularity for optimal energy consumption, along with other rational advantages, such as size and cost. However, the dynamics of power conversion within the machinery in such customs are repetitive and sometimes unnecessary. Eliminating recurring processes can remove inadequacies such as complex design, dedicated control schemes, and high maintenance costs that arise from them. The article presents a two-level DC distribution line for consumers who use a wide range of electrical loads. The work integrated the output of a three-phase SCR-controlled, power-efficient AC-to-DC converter and the output of a solar cell to build the dual DC grid. The performance analysis of the novel framework for cataloged loads was conducted using simulations, and the outcomes were observed to be satisfactory.

KEYWORDS: Rectifier, inverter, solar power, DC grid system, buck-boost converter.

INTRODUCTION

The daily electricity consumption of a society is directly related to the standard of living [1], [2]. Bangladesh, contributing 2.14% to the world's population and ranked 37th globally for electricity production, is seeing a rise in its electricity requirements for the day-to-day lives of people who use electrical equipment for household purposes. According to the World Bank Open Data Base, about 46% of energy consumption in Bangladesh is due to domestic load, and overall per capita consumption rose by 509% in 2022-2023. The numbers indicate that it is high time the country focuses on distribution efficiency in this sector for national and international benefits.

The gadgets used in modern life provide functionality in a convenient way, and it is required that they are energy-efficient as well. The complex designs behind the fancy look and optimum usage of refrigerators, washing machines, air conditioner cum heater, dishwasher, smart televisions, multifunctional ovens, etc., are often paired with a special scheme: AC (1- $\emptyset$, 3- $\emptyset$) used to obtain DC; the DC level further uses a 3- $\emptyset$ inverter (PWM, SPWM, etc.) to produce a suitable AC output [3]. The controlled (magnitude and frequency) output operates 3- $\emptyset$ motors, BLDC motors, etc., for power efficiency and appropriate control of speed and torque for variable loads.

This study aims to replace this repetitive power distribution pattern at the consumer side. Market Research Future terms the Asia-Pacific region, where Bangladesh is situated, as the fastest-growing market for inverter technology. It is imperative that there should be means for the energy consumption style in Bangladesh to blend into the clean energy trend through smooth adaptation and widespread integration. This proposal progresses towards a more efficient design and performance without needing a profound change in the traditional AC distribution system.

To serve the interests of clean energy and the trend of renewable energy sources, the study also integrated a solar system as a part of the proposed scheme. The solar-powered grid is designed to power low-voltage and low or medium-power equipment. In fact, to ensure efficient electricity consumption and reverse the rising trend, the study also focused on the indispensable integration of solar power in the most efficient way possible.

LITERATURE REVIEW

Smart home appliances come in various ratings that often vary from a few watts to several kilowatts [4]. The loads can be categorized according to their current and power requirement [5]. Such a categorical distribution can be convenient for splitting the distribution system for supply efficiency at the user end. AC can be suitable for the transmission of power, but a DC distribution system is more efficient [6], [7]. When used along a proper set-up, a DC distribution system is able to provide stable and sometimes more efficient performance than an AC distribution system in households and industries [8], [9].

There is an increase in the number of home appliances with inverter technology that use rectified output of either 1- $\emptyset$ or 3- $\emptyset$ AC supply. [4], [5] The instruments basically run from the rectified DC input. The progress in inverter technology, the trend of renewable energy resulting from on-

site production of DC power sufficient for domestic use. DC power can eliminate the 3.75% conversion efficiency loss associated with the additional step of AC-DC conversion and positively affect the efficiency if used as a centralized system [6]. The potential of the DC system to bring out an improved controlled performance thus positively contribute to considering a DC grid for domestic use.

The previous studies have opted for various methods, such as developing a DC link system from solar powered PV cells, obtaining DC from rectification of available AC supply, etc. [5], [11]. It was observed that one singular supply was incapable of driving variable power loads. Step-up or step-down of the obtained voltage was an obligatory union in the designs. This study proposes a parallel integrated system of the PV-cell DC supply of a lower power rating with an AC-main rectified output of a higher power rating, in contrast to that.

The demography and seasonal weather of Bangladesh have promoted solar system-based DC power generation as frequently and proficiently [12], [13]. The works explored the advantages of DC grids powered by such secondary sources and their implementation in rural households. On the other hand, the energy demands in urban areas are higher, and the use of power-efficient equipment is encouraged [14], [15]. The pattern of electricity consumption among urban consumers shows that a higher-order DC supply can fulfill the requirement well.

This work establishes a novel scheme to bring the two levels of DC voltages into a single system. The primary focus was to utilize the available energy resources without complicating the system with additional electrical and electronic circuitry. The study also discussed the potential of the proposed scheme in comparison with the limitations that might be faced during the execution stage. Simulation data were presented that fairly reflected a practical scenario under the suggested plan.

METHODOLOGY

The use of inverter technology requires AC to DC conversion. A considerable amount of power is lost during the process. For an instant, a rectifier diode has 0.6V of drop across it, causing 0.6W of power dissipation on it per ampere of current flow. The number of diodes in the rectifier circuit used in equipment can exceed the number of four. This DC is used to produce AC of a certain magnitude and frequency that will run 1- $\emptyset$ and/or 3- $\emptyset$ motors like PMSM, IM, BLDC, etc. A DC distribution grid can cut down on the requirement for AC-DC conversion, and the conversion loss can be eliminated. The savings can be as high as tens of watts per piece of equipment. This can also reduce the size and cost of the equipment.

Considering the requisite input current (and hence, input voltage level) [4], [5], the household item can be categorized in following levels:

- i. **Low Power Rating (LPR):** Lights (mostly LEDs), fans (with DC/BLDC motors), Wi-Fi routers, laptops, audio-video equipment, etc. This type of equipment consumes a few watts.
- ii. **Moderate Power Rating (HPR):** Small room heaters, hair dryers, small refrigerators, blenders, water filters, etc. This type of equipment consumes around a kilowatt.
- iii. **High Power Rating (HPR):** Smart refrigerators, air conditioners, induction cookers, dishwashers, washing machines, water heaters, etc. This type of equipment consumes a few kilowatts.

This work proposes an integrated DC grid system (Figure 1) for household implementation. The DC grid will replace the traditional single-phase AC distribution system. It is composed of two separate levels:

- i. **Low Voltage (LV) Line:** This will be run by the installed solar-powered PV cells and storage battery of suitable ampere-hour ratings.
- ii. **High Voltage (HV) Line:** This will be operated by the highly efficient SCR rectified output from a 3- $\emptyset$ AC supply.

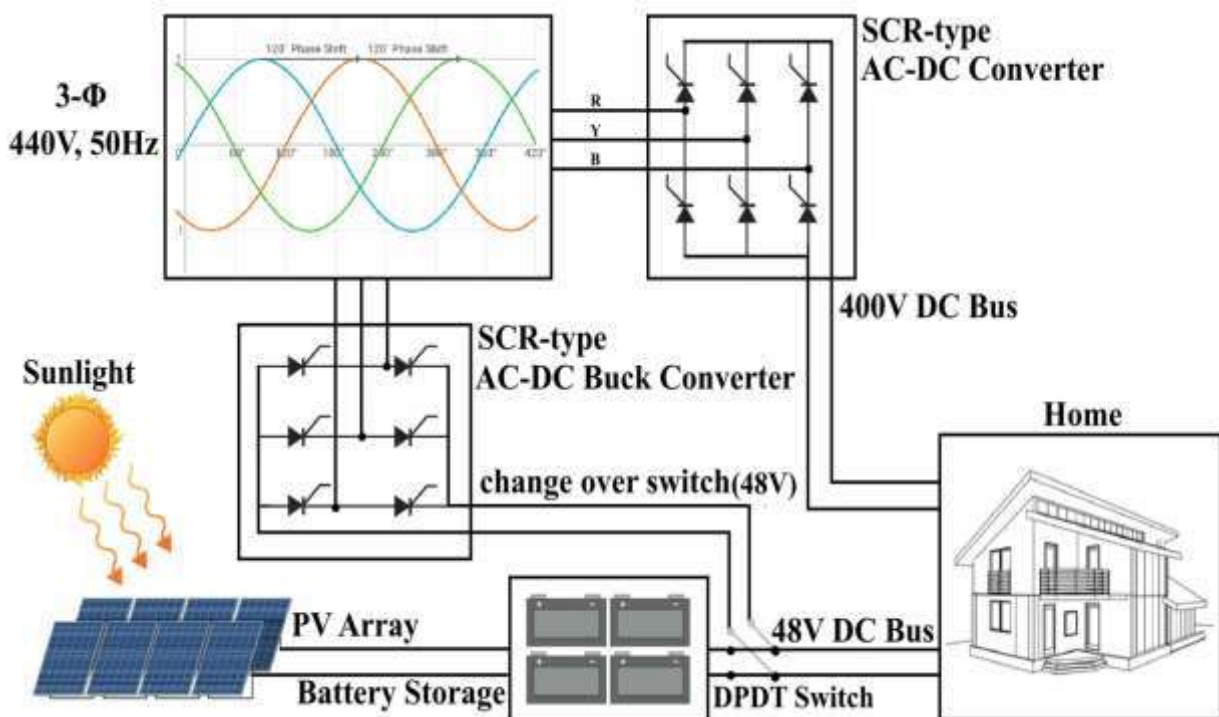


Figure 1: Schematic diagram of integrating solar-powered PV-cells and output from a 3- $\emptyset$ rectifier to design a two-level DC grid architecture for household applications

The two-level DC bus will be wired within the household premises for daily application. The equipment of the LPR and MPR group will be directly connected to the LV 48V line. It will supply power during the daytime and certain hours after sunset, depending upon the storage capacity of the installed battery.

The equipment of the HPR group will receive power directly from the HV 400V line. Such an arrangement will reduce the necessity of using a rectifier circuit at the input of each piece of equipment that needs the DC voltage for its circuitry.

Designers of home appliances will now design their equipment, choosing either of the two DC voltages appropriate for its operation in accordance with the voltage and power ratings.

DESIGN AND SIMULATION

i. Composition of the HV 400V Bus

The 400V bus is powered from the output of the SCR-controlled 3- ϕ rectifier. For loads of higher power and voltage rating, obtaining DC from 3- ϕ is advantageous over obtaining DC from 1- ϕ [15], [16]. The output has a higher average DC value, less ripple, and harmonic distortion, and the copper requirement is lower. An SCR-controlled rectifier can power 10's of kilowatts of load. It can be added here that a simple uncontrolled diode rectifier can also produce 400V DC from a 3-phase 440V AC supply. In some of these types of rectifiers, the small ripple produced in the bus can be eliminated by using a filter, and the 400V DC bus can be used.

This 400V DC bus will replace the traditional single-phase AC supply system in a building. The installation of the DC bus throughout the building will enable the inverter-operated equipment of higher power ratings to run. The equipment will save on the separate circuits in each built-in rectification circuit in all the household appliances. Additionally, the available bus system will enable and encourage the use of DC-motor-operated equipment for efficient output and a clean environment.

ii. Composition of the LV 48V Bus

The 48V bus receives power from PV-cells installed (generally, on the rooftop) for converting solar power. It will be used during the daytime.

The battery capacity will be enough to support the demand of the connected bus.

The 48V DC supplying critical loads will have a backup from a 3- ϕ SCR-controlled rectifier. The reason is that the fans and lights are connected to it around the clock. The LV bus may fail due to insufficient battery charge or power generation failure due to bad weather. An automatic or manual changeover switch will perform the necessary operation.

Some home appliances may require separate levels of DC voltages for their operations. The equipment can be designed to have 48V DC as input. It can also be provided by DC-DC converters as per the requirement. One such arrangement is shown in Figure 2 (a).

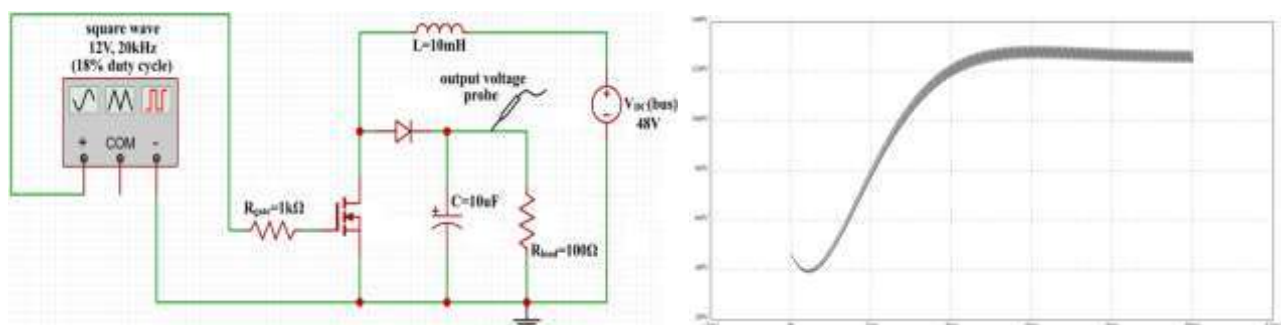


Figure 2: (a) Boost converter for obtaining 120V DC from a 48V DC bus; (b) 120V DC output from the boost converter.

The MOSFET is driven by a 12V, 20kHz pulse. The duty cycle was set to 80%. The DC converter of 140W produces an output of 120V DC, which drives a load of 100 Ω of 144W. The output power was found to be 96% of the input power. This depicts an efficient conversion obtained by the boost converter. An additional filter can reduce the ripples. Figure 2 (b) shows the available output voltage.

A similar type of arrangement can be used for charging the batteries of electric vehicles. The battery charger can use 400V DC or 48V DC. The simple method requires less maintenance and can handle more power.

CONCLUSION

The urban household typically consumes around 2-5kW load. The copper capacity estimation for the designed 400V DC bus is 2.5A per kW load. For the 48V DC bus, the estimation is 20A per kW.

The SCR-type of rectification deteriorates the power factor in the AC line. To compensate for this, a power factor correction circuit is placed at the input of the SCR-type rectifier. In fact, the inverter appliances require a diode rectifier. If not, the power factor of the connected AC line is affected. Most of the appliances do not have a power factor compensator as they want to keep the cost of the equipment low. In the proposed 400V DC grid line system, a single power factor correction circuit will compensate for all the equipment connected to it.

The 48V DC bus from the solar panel will reduce the load on the national grid. As the solar power is not grid-connected via an inverter, the cost of installation will be much less. Such an isolated solar DC power system has higher reliability, that is, less failure-prone, and so will need less maintenance. This is also cost-efficient, and the investment is affordable to the building owners. Campaigning of such an endeavor nationwide may be done to encourage the usage of renewable energy in remote areas, even with a subsidy if required.

Future Scopes

The clear merits of 400V DC cum 48V DC micro-grids can contribute to designing smart homes more efficiently in terms of electrical wiring, space-saving, and energy conservation. The reduction in the requirement of additional units such as power factor correctors, rectifiers, or multi-

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level converters can positively contribute to reducing equipment size, their construction cost, and the addition of other utilities. The low-level DC can be designed to power DC-powered freezers, DC-powered air conditioners, etc.

The power electronics modules, like inverters and buck-boost converters, are commercially available in vast quantities. These modules are all PCB-based and are of small sizes. New methodologies using such modules of different power and voltage ratings in the proposed setup can be devised.

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