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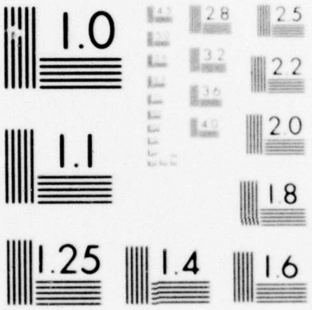

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ADVANCED SEMICONDUCTOR TECHNOLOGY FOR ALTERNATE ENERGY SOURCES – D-C TO A-C INVERTERS,

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ADVANCED SEMICONDUCTOR TECHNOLOGY FOR ALTERNATE ENERGY SOURCES - D-C TO A-C INVERTERS

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ABSTRACT

Alternate or advanced energy conversion methods frequently require d-c to a-c conversion since the energy output must be synchronized with an existing utility grid. The objective of this paper is to describe various preliminary system concepts for interfacing advanced solid-state energy converters to the utility grid with a significant potential for reducing initial capital investment.

Recent ERDA sponsored studies[1,2] have identified the solid-state d-c to a-c inverter as a key element for further development. These studies indicated that an inverter synchronized to the utility grid can directly transform solar photovoltaic array generated energy to local load (residence) demand with any excess energy feedback to the utility grid. Where the solar energy is insufficient to supply the local load, it is supplemented by the utility grid. Several key issues were identified in the referenced studies. One of these involved the considerable weight and cost associated with the d-c to a-c Inverter/Transformer vs a Transformerless Inverter that would have "Float" with respect to the power grid return. This paper addresses this issue as well as the anticipated solution to the problem using advanced semiconductor technology.

Considerable emphasis is placed on the expected technology/cost advantages which could be anticipated using recent breakthroughs in the area of AℓGaAs/GaAs photovoltaic materials by means of the CVD process[3,4] and Planar Solar Concentrators (PSC's)[5]. As an example, a combined photovoltaic/inverter system has been postulated to provide peak load sharing using utility grid feedback as suggested by Stater-Goradin.[6]

The primary emphasis of this paper is placed on the d-c to a-c inverter technology integrated into an overall alternate energy system. The objective being to (a) minimize initial capital cost, (b) maximize energy conservation, and (c) defer utility capital commitments.

1. INTRODUCTION

Recent studies[1,2] sponsored by ERDA/NASA concluded, among other things, that the most economic configuration for a Photovoltaic Residential Prototype System would omit local load storage (batteries) in favor of utility grid feedback. Figure 1 illustrates how an ideal system of this type might function. The flow diagram illustrates a photovoltaic array interfacing through a power conditioning unit to the local load and the utility grid. The introduction of large numbers of systems would result in a displacement of fuel consumption and also result in considerable energy conservation. Fundamentally, there is no reason why a system of this type cannot be placed in operation now except for the high initial cost.

Energy management techniques may have to be developed in order to optimize the stability and control of the utility network, however, this should not be a limitation. Significant capital deferment might be achieved in areas where peak power demand during the summer months can be attributable largely to running 220 V air conditioning compressor systems during peak insolation periods. Electric space heating does not appear economical compared to a thermal system which might be considered as part of the photovoltaic array[6].

It should be pointed out that rugged and reliable light-weight photovoltaic arrays offer one of the most attractive means for retrofitting existing residences to the utilization of Solar energy conversion, hence, excessive weight build-up for a thermal heating system could be counter-productive, although forced air ducting might be one way of overcoming high weight.

Recent advances in making solar photovoltaic cells from AℓGaAs/GaAs (Gallium Arsenide) using the Chemical Vapor Deposition (CVD) process[3] has opened further opportunities to accelerate development of low-cost photovoltaic arrays. Gallium Arsenide photovoltaic cells are characterized by increased output with temperatures up to 100°C which makes this type of device extremely attractive for Solar arrays using concentration.[7]

A very recent breakthrough in multiple-dye Planar Solar Concentrators (PSC's) suggests that up to a 100:1 concentration ratio would be obtainable with a 0.75 conversion efficiency.[5] Combining the GaAs CVD process for fabricating photovoltaic strips with the PSC's could provide a very low-cost system. Given that an array could be fabricated at a reasonable cost, it would also have to include a d-c to a-c inverter for synchronization to the utility grid. It is conceivable that this inverter could be extremely light weight using advanced semiconductor technology, such as, power field effect transistors (Power FET's). The controls for this inverter can be readily programmed in advanced microprocessor chips at very low cost. The following sections will discuss these aspects in more detail.

II. UTILITY GRID FEEDBACK

Figure 2 illustrates a flow diagram for utility grid feedback. When the solar array power output capability allows the inverter output power to exceed the house load demand the excess power flows back into the utility grid which, in fact, would cause the Watt-Hour meter to reverse direction and in theory, the homeowner would be selling power to the utility company! Aside from the economic implications of this technique, several technical aspects must be examined. One of these involves the type of d-c to a-c conversion that is implemented. Simple d-c to a-c converters convert a d-c voltage to a squarewave of a-c voltage. The squarewave is rich in harmonics, and although a single photovoltaic system (~10 kW) feeding a 10 MW grid will have a negligible effect on overall line distortion, many such systems can have a serious effect on line voltage quality and can have adverse effects on induction motors and other reactive loads that "heat up" from 3rd, 5th, etc., harmonics. It is safe to assume that a sinewave d-c to a-c inverter would be preferable, and in the case of widespread usage, mandatory. Present sinewave inverters used as standby uninterruptable power sources (UPS's) are heavy (100 lb/kVA) and expensive ($1000/kW) due in large part to the reactive components (Transformers, Inductors, and Capacitors). The semiconductors (SCR's and Rectifiers) are light, and although initially expensive ($100/kW) have been decreasing in cost due to the highly competitive and automation-intensive nature of the modern semiconductor industry. It is this semiconductor area of progress that offers the best hope for drastically reducing the cost of d-c to a-c inverters which could be produced without using reactive components.

Present SCR inverters require L-C networks for commutation and current smoothing as shown in Fig. 3. For a 10 kW system (generally accepted size for residential usage) the smoothing inductor would be on the order of 30 mH and weigh about 70 lb. The commutating capacitor would be on the order of 1500 to 3000 μF and of comparable weight. Both of these components use Copper, Aluminum, Tin and high-grade magnetic material which presently averages (in the aggregate) of around $2/lb without labor. In addition, these are labor intensive components that require considerable manual effort. Quality control standards must also be high. It is evident, therefore, that an all semiconductor d-c to a-c inverter would eliminate the need for these baseline cost components and therefore, open the door for a truly low-cost system.

Substituting transistors for the SCR's in Fig. 3 would not eliminate the need for inductor L, or capacitor C since the line voltage basically performs the commutation process. What is required then? The answer is that an all-electronic alternate of Fig. 3 must be developed which would use advanced semiconductor technology using a new system configuration. This postulated system is discussed in the next section.

III. POSTULATED SYSTEM

This all semiconductor system is illustrated in Fig. 4. The system would operate as follows:

(1) The Solar array would produce a d-c voltage which would be switched in sections by the controls in the advanced d-c to a-c converter to produce sinusoidal waveforms which would closely duplicate the utility line voltage. This would be accomplished by using an advanced microprocessor circuit which would monitor (a) the utility line voltage, (b) the characteristics of the residential load, and (c) the solar array output (including maximum power tracking) and the status of all internal switching circuitry.

(2) When the control circuits establish that the array power can be transformed to the load and utility interface, the properly phased and synchronized a-c power from the array will be gradually applied.

(3) Since turn-on and turn-off transients caused by refrigerators could be damaging to the electronics, semiconductor surge arrestors would also be introduced as well as lightning and heavy duty utility power surge arrestors (MOV's). Also, the heavy transient loads will be supplied by the utility line since these do not contribute to appreciable energy loss but would cause the d-c to a-c inverter to be overdesigned for line and load surges.

(4) When solar insolation is minimum (at night), the array power would not be available and the inverter would disconnect from the power line. During peak insolation periods, the heat in the planar solar concentrator (Concentration Ratio of 100 to 1) combined with heat loss in the inverter (about 5 percent of the inverted power would result in heating) could easily be dissipated by free convection provided there is air space between the roof and the assembly. If the heat were to be used for space heating, it would probably be most effective to use lightweight aluminum tubing to air-cool the array and augment the air conditioning or heating units with conventional air compressors.

Although this postulated system could probably be used in a wide variety of climatological locations, it appears more likely to be the most cost effective where air conditioning costs are high and escalating. The two most likely locations are Southern Florida and Phoenix, Arizona. The lightweight structure and fairly high displacement of electrical energy could be particularly appealing to mobile home owners. One problem may arise however. The peak demand for air conditioning can extend beyond the insolation period. This could require some local energy storage. Storage can be justified only if the utility offers an attractive inducement (peak power rates) or if there are tax benefits. A new law signed recently by Governor Brown of California allows up to a 55 percent State Income Tax deduction (itemized to a maximum of $3000) for solar or alternate energy equipment.

Similar laws at the Federal level could provide the wherewithal to convert many existing fixed income homeowners with a system of the type described herein. If we assume that the economic environment for such a system were to be viable, it is also necessary to consider some of the other requirements that would drive the design, in particular, integrating the d-c to a-c converter system with the residence and the utility.

IV. INTEGRATION OF THE D-C TO A-C INVERTER

The first rule to be observed in this effort must address the initial capital cost of the system. The planar solar concentrator should reduce the effective cost of the Gallium Arsenide Photovoltaic Array by roughly a factor of 25. Recent advances in Chemical Vapor Deposition of $A\ell GaAs/GaAs$ indicates that cells with up to a 20 percent conversion efficiency might be fabricated in mass production at costs of $2.50 to $5.00/peak W. A 25 to 1 reduction over cost due to the PSC technique would result in an overall array cost of 10¢ to 20¢/peak W, or $100 to $200/peak kW. The all solid-state d-c to a-c inverter could easily fall in the same category. Since this is still very speculative, let us assume that an overall cost for the assembly shown in Fig. 4 came to around $400/peak kW and one were to invest $4000 in this system (10 kW peak). As a result, one would have bought 10 peak kW which would tend to average around 50 kWh per day during the summer months and somewhat less in the winter. At 6¢/kWh this is approximately $3.00/day or about $90/mo to offset utility costs. If one assumes an average of $60/mo savings for the year, this is a return of $720 in the first year. If the $4000 were borrowed at 10 percent annual interest, the $400 of annual interest would be the offset for pay back by the energy with a net gain of $320/year. However, it should be pointed out that the interest could also be a deductible expense and hence, for a 33 percent bracket this would add back another $133 to the $320 for a net return of $453/year.

There is no reason to believe that this system should not last at least 10 years and and possibly 20, hence it could be paid off early and simply reduce utility costs after say 3 to 5 years. Additional square footage could be purchased and hence, offset more non-renewable energy. The excess could then be sold by the utility for Electrolysis (Hydrogen production) or industrial use. Fortunately, it is possible for industry to adjust schedules to take advantage of peak energy availability and this might be accomplished without significant changes in the present work schedules.

There are two possible ways to integrate the d-c to a-c inverter with the Solar array and utility grid in order to minimize initial capital investment. One method would treat the d-c to a-c inverter as a separate entity with appropriate wiring between the array and the utility grid (as shown in Fig. 5) and the other would integrate the d-c to a-c inverter with the array (as shown in Fig. 6). The latter method holds the most promise since this reduces the wiring costs and is more amenable to automatic production of Array/Inverter. Figure 7 shows a block diagram of a simplified equivalent circuit recently patented by the author[8] which can accomplish the results intended for the configuration shown in Fig. 6.

The block diagram illustrates how the array can be subdivided to provide isolated d-c source to semiconductor bridge circuits which can be controlled by a microprocessor to produce two or more quasi-sine waves (or other wave forms) which are then added vectorially to provide a variable amplitude which is also controlled by the microprocessor (or other type of computer) to synchronize the a-c output to the utility line. Either bipolar transistors or field effect transistors can be used to perform the switching. Protective devices such as, semiconductor surge arrestors can be included to prevent damage to the array/inverter by utility power surges or local load transients. The most significant aspect of this technique would be the absence of heavy and expensive reactive components coupled with a lightweight, highly producible set of hardware.

V. KEY ISSUES

Before advanced semiconductor technology can be extensively applied to Alternate Energy sources, several key issues must be resolved. Some of these issues are given as follows:

(1) The optimum energy payback period

(2) The optimum cost payback period

(3) The target initial cost to the customer vs the number of units that could be produced and sold

(4) Isolation/Safety and protection of the Array/Inverter and personnel.

(5) Incentives for the semiconductor manufacturer to enter this area of business.

At present, these issues are being addressed by various individuals, agencies and industries on a piecemeal basis. As an overall National (or international) energy policy takes shape, it should be possible to channel the highly inventive and cost reduction processes established by the semiconductor industry to provide an innovative, utilizable source of alternate energy (such as photovoltaic) which could be readily integrated into the existing electrical networks.

VI. SUMMARY

As a result of this preliminary study, it is evident that advanced semiconductor technology can provide significant breakthroughs in cost and an early realization of solar energy displacement of non-renewable fuel. Utility grid feedback and lightweight photovoltaic collectors using advanced semiconductor technology appear to be very compatible with existing residences and utility networks. The use of gallium arsenide photovoltaic semiconductor material and multiple-dye planar solar concentrators may provide a significant reduction in array cost. Present d-c to a-c inverters are too costly, however, by using advanced semiconductor technology and greatly reducing or avoiding reactive components can provide a significant lowering of initial capital investment. The paper outlines one of several ways such a system might be arranged provided the key issues associated with energy policy can be resolved.

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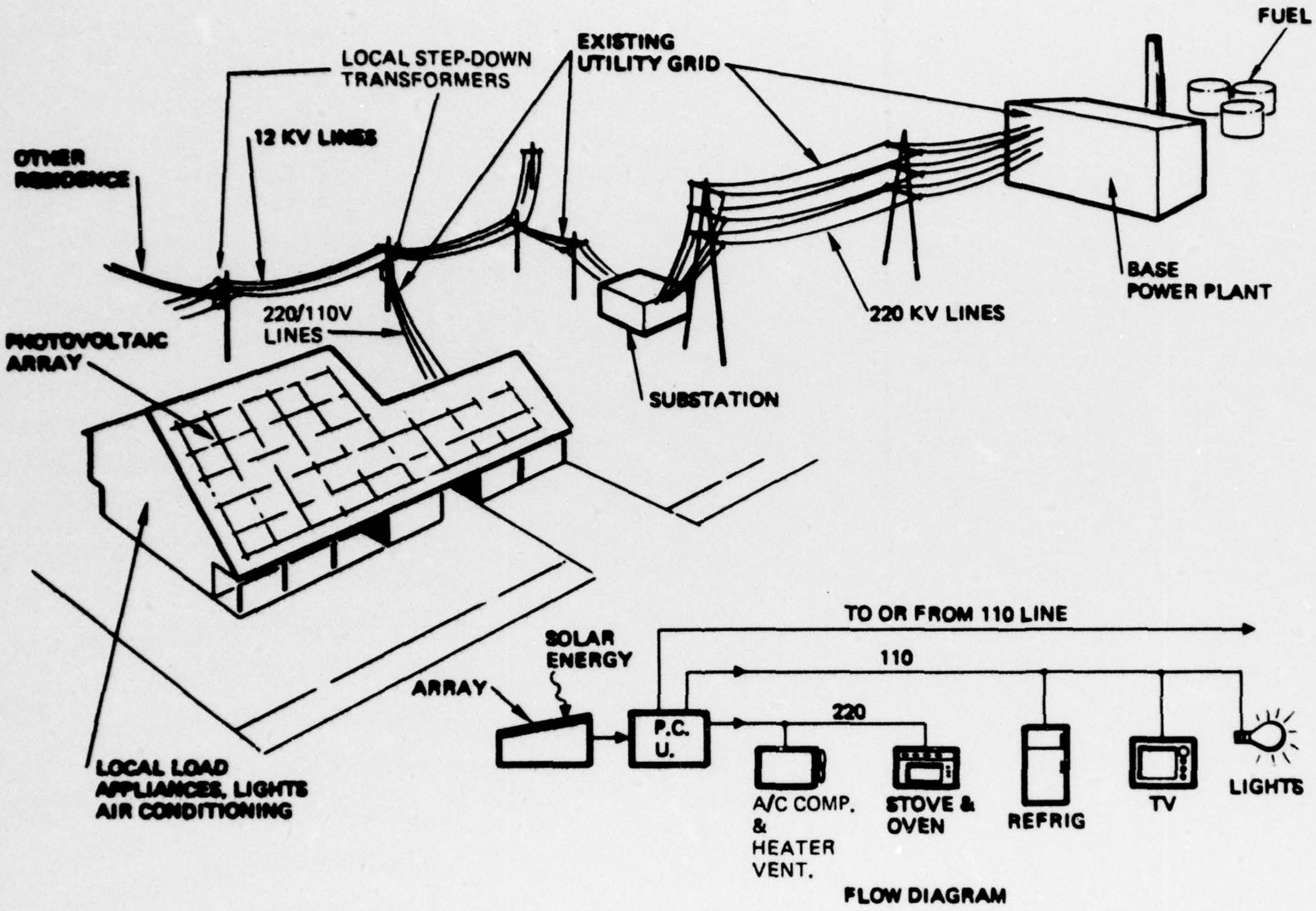

Fig. 1. Illustration of Residential System with Existing Utility Grid Incorporating a Photovoltaic Array and Power Conditioning Subsystem

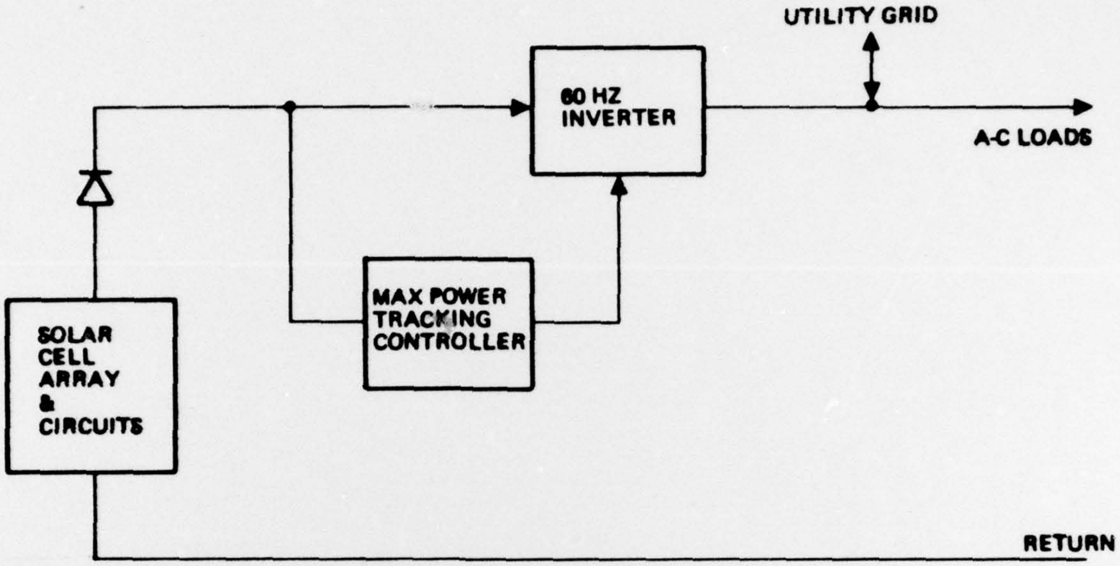

Fig. 2. Simplified Block Diagram of Utility Feedback System

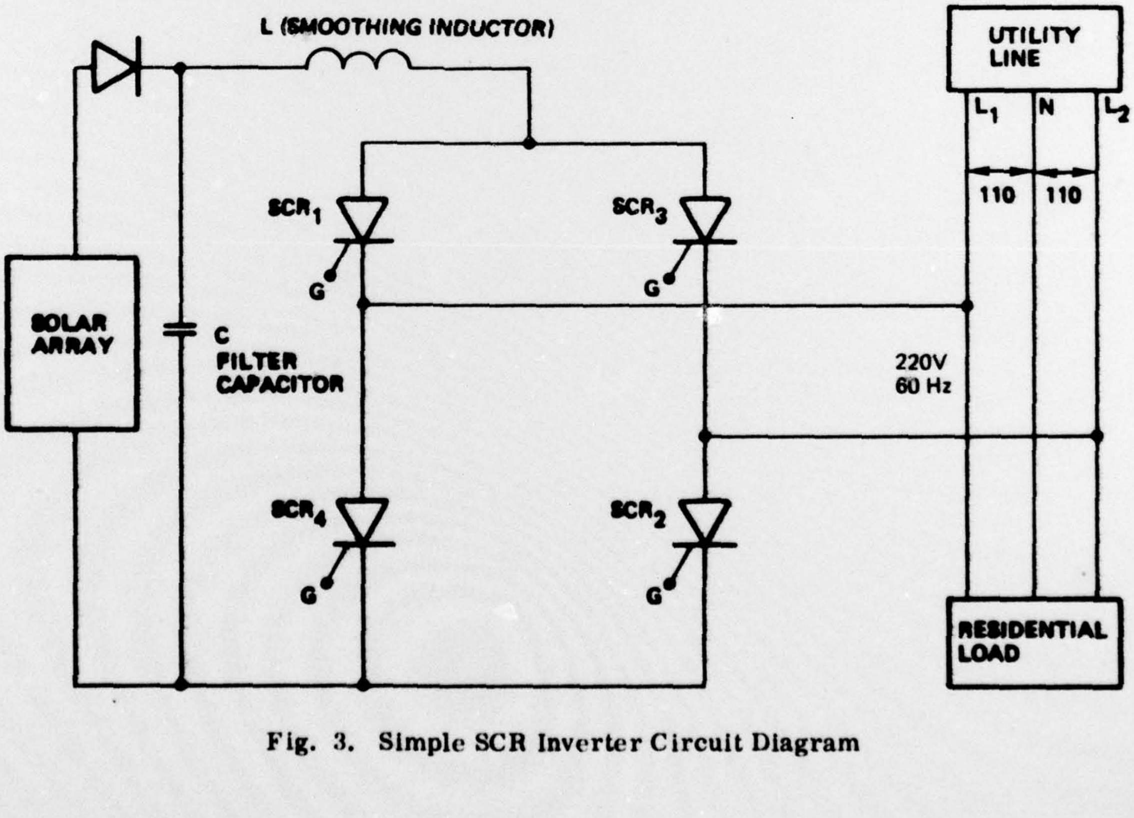

Fig. 3. Simple SCR Inverter Circuit Diagram

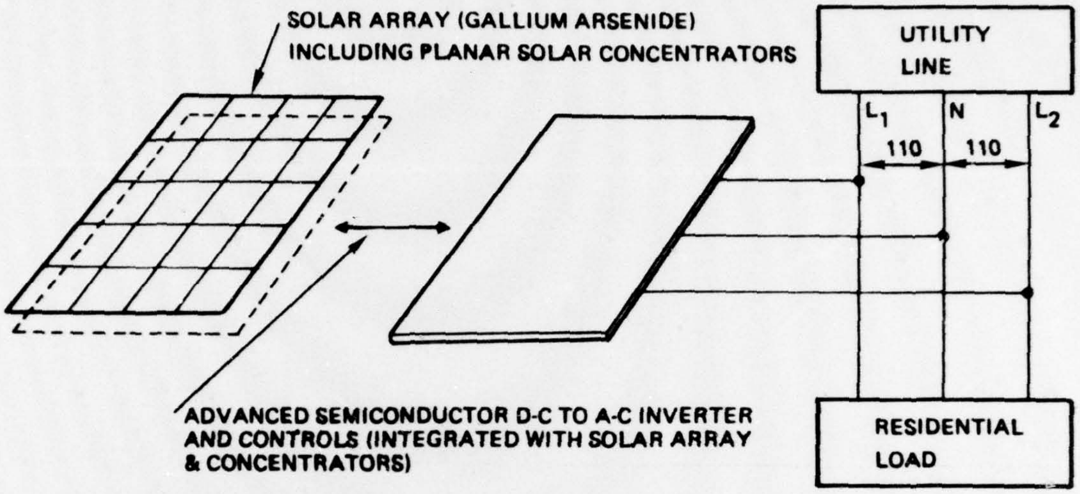

Fig. 4. Postulated All Semiconductor System

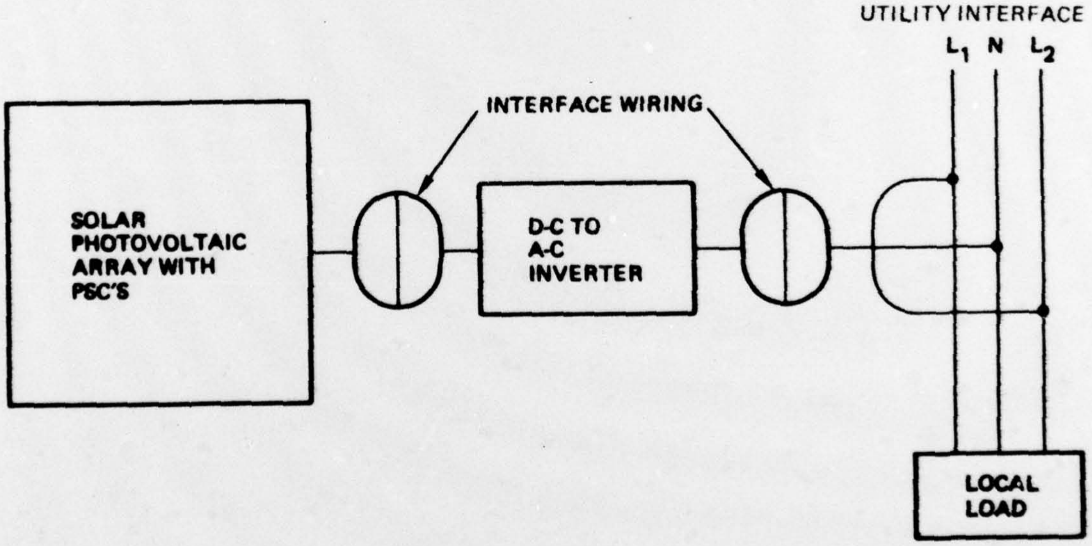

Fig. 5. Array and Inverter Integrated as Separate Subassemblies

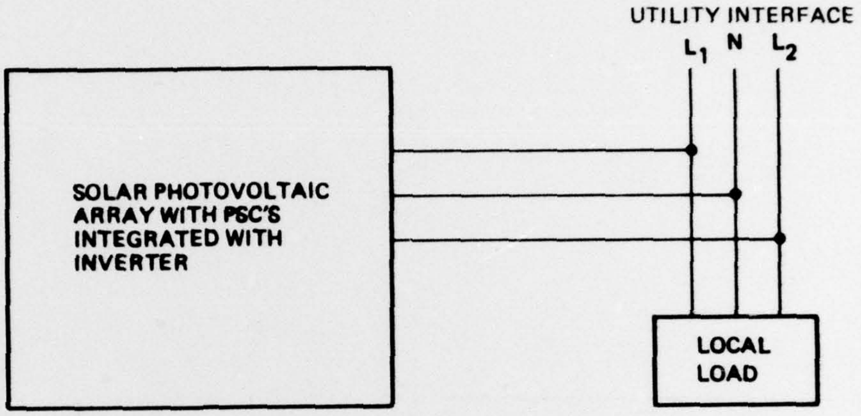

Fig. 6. Integrated Array and Inverter as One Assembly

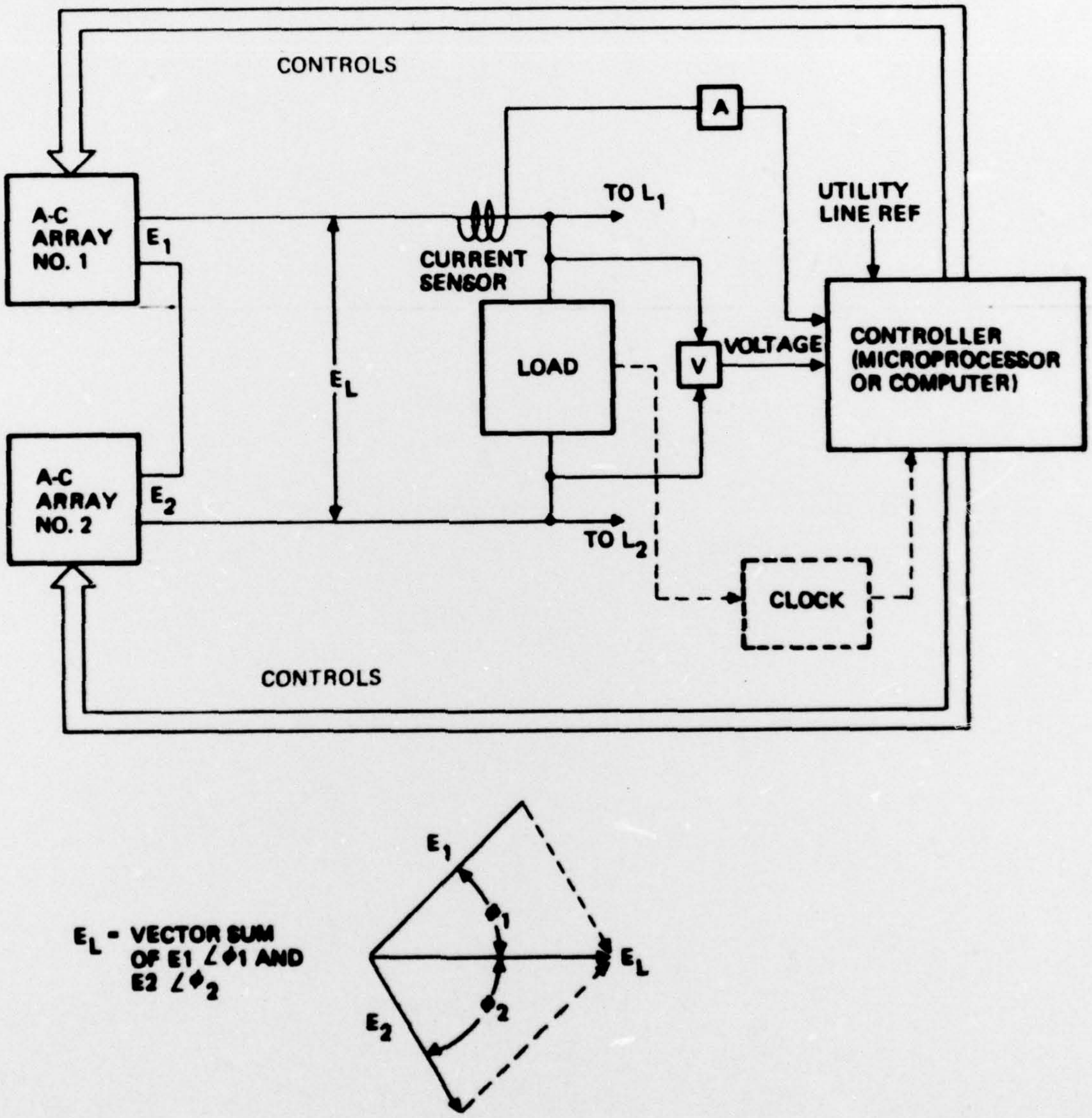

Fig. 7. Block Diagram of Advanced Solid State Inverter Circuit