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Analysis on the performance of a grid connected PV –ECS system using Electric Double Layer Capacitor

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Abstract— Energy and power plays a vital role wherever men lives and works-in industry, agriculture transportation and for many other domestic purposes etc. Among the various sources of renewable energy, photovoltaic (PV) has proved its potentiality as a long-term, inexhaustible, environmentally friendly and reliable energy technology. This paper describes the performance of a grid connected PV –ECS system considering the variation of PV output due to the yearly variation of solar radiation and weather condition. Here we have developed a grid connected PV based distributed system using Electric Double Layer Capacitor (instead of conventional battery). To get various advantages, EDLC is used in combination of electronic circuits which is called Energy Capacitor System.

Index Terms— Photovoltaic (PV), Energy Capacitor System (ECS), Electric Double Layer Capacitor (EDLC) Power, Conversion System (PCS), Maximum Power Point Tracker (MPPT).

1 Introduction

Power provides our homes with light and heat. The living standard and prosperity of a nation vary directly with increase in use of power. Due to the global warming effect, oil crisis of 1970, nuclear disaster of 1986 and some other environmental issues people have been searching for a renewable source of energy that can be used as an alternative to the fossil fuel. As a result, the use of photovoltaic systems is increasing not only in the poor countries as a substitute of grid electricity, but also in the developing and developed countries as a green source of electricity.

The distributed power generator specially the one using photovoltaic (PV) is drawing the attraction of users. Although the cost of PV system is yet higher than that of conventional generating system, the use of PV based system is gradually increasing due to the maintenance free, long lasting and environment friendly nature of PV. Scientists, all over the world, are doing various types of researches to overcome the limitations of photovoltaic to make it more popular. For proper utilization of solar energy, some sorts of storage devices are necessary with the system. Generally, photovoltaic systems having back-ups are constructed using lead-acid batteries [1-6]. But lead-acid batteries suffer from some problems, like, short life cycle, low power density and for some varieties the nuisance of continuous maintenance. In this point of view, in this work, a photovoltaic system has been constructed using a new storage device called Energy Capacitor System (ECS). The ECS has a very long life cycle, high energy density and high efficiency. The lasting period of the ECS is 3000000 cycles, whereas that of the lead-acid batteries is 1000 cycles. Using this new energy storage device all the problems of the battery has been eliminated.

The proposed PV-ECS system can be run in two different modes- (1) optimal economic mode and (2) optimal load leveling mode. . First mode is to save the cost of electricity by producing power by the PV panel and using the stored energy in the ECS in peak hours (time duration of the day when the price of electricity is higher) instead of the grid power. The second mode is load leveling, i.e., to level the power taken from grid line using the power of the PV and the ECS. To fulfill these two modes, it is necessary to set how much power will be taken from grid line (hereafter this power will be referred as “buy power”) before the system starts its daily operation. To set this value properly, it is necessary to know how much power will be produced by the PV panel on the operating day

The performance of the system depends not only on the modes of operation but also on the power generated by PV panel which varies due to the yearly variation of solar radiation and weather condition. A procedure is developed to calculate the daily solar radiation and PV output power using one-day-ahead weather forecast [6-7].

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Again, a simulation program of the system has been developed [7]. The aim of the estimation procedure of PV output and the simulation program is to run the system properly so that it can provide optimum economic benefit (save the cost of electricity) and to level the load.

Different simulation is used to visualize battery power, state of charge, battery charging and discharging condition, comparison of solar radiation and PV output, how PV output is involved with battery charging and so on. Simulations of different situations help to give clear concept of the performance and working status of solar system. The validity of this simulation program has been verified by comparing the simulated results with the practical operating ones. Thus we get the optimal economic benefit of grid connected PV-ECS system.

output of the PV panel, used in our system, is 1296W. The construction of the system is described in the following sections.

2 Description of the System

A simplified block diagram of the system is shown in Figure 1. This diagram shows the main unit-blocks of the system and the directions of power flow in the system. On the other hand, Figure 2 gives another block diagram that shows the main unit-blocks, control lines and the measurement-points of different parameters. As shown in Figure 1, the MPPT unit supplies the PV output to the PCS or EDLC bank; the PCS unit can supply power in both directions. Similarly, the EDLC bank can supply power in both directions, i.e., it can be charged and discharged, and the grid power can flow in both directions, i.e., the system can "buy power" from the grid line or sell power to it if necessary.

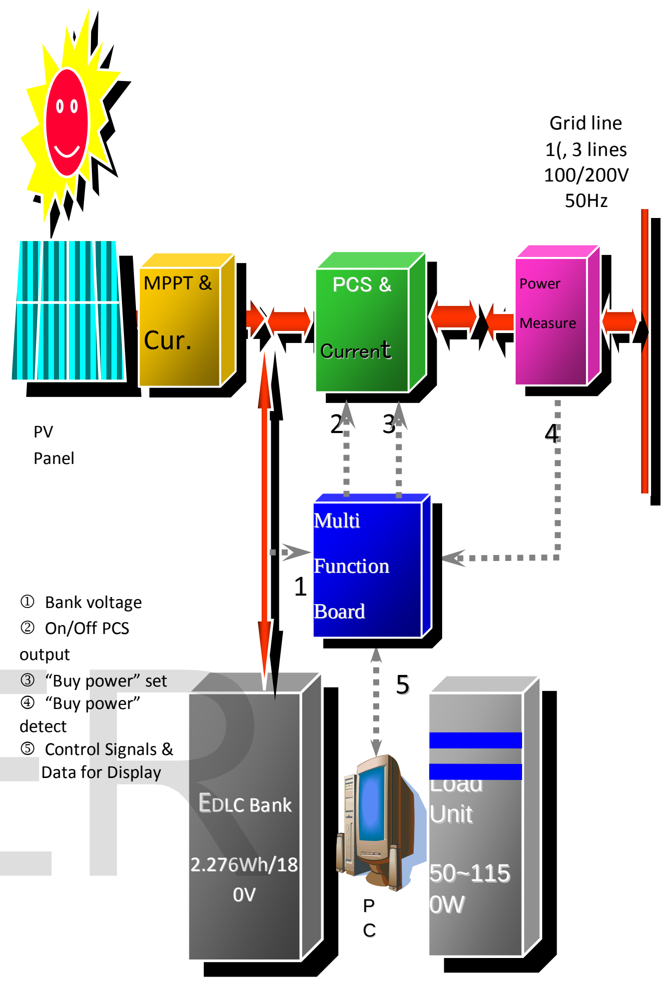

Fig 1: Block Diagram of the System (showing directions of power flow)

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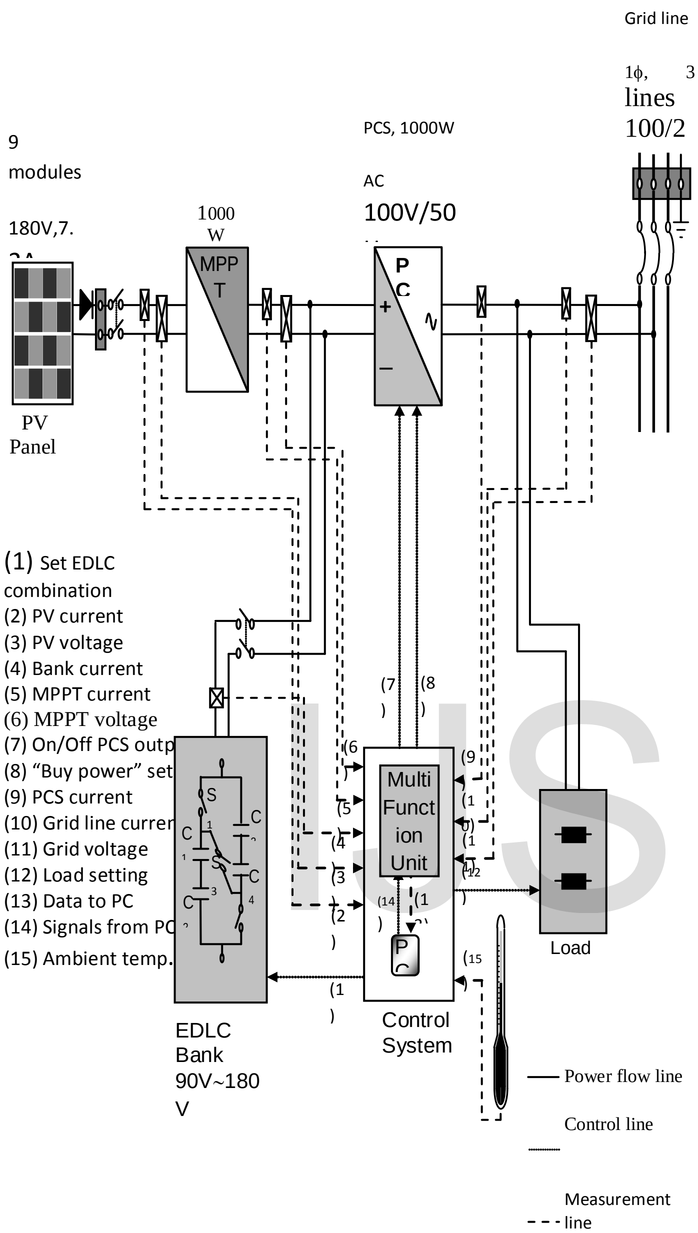

Fig 2: Block Diagram of the System (showing control lines and measurement points)

As shown in Figure 2, current and voltage are measured at the output terminals of the PV unit, i.e., at the input terminals of the MPPT. The current and voltage at the output terminals of the MPPT is also metered to calculate its efficiency. The voltage measured at this point, also gives the DC voltage of the bank and the PCS. The current of the EDLC bank is measured and the DC input/output current of the PCS can be calculated by adding the MPPT output current and the bank current. Using these parameters, the PV output power, MPPT output power, charging/discharging power of the EDLC bank and the input power of the PCS unit can be calculated.

Again, the current at the AC terminals of the PCS unit is measured. The AC voltage and the current of the grid line are also metered. Here also, the measured voltage gives the load voltage, line voltage and AC voltage of the PCS. By adding the AC current of the PCS unit and that of grid line the load current can be calculated. Hence, the power in the AC side of the PCS unit, power taken from (or sold to) grid line and the load power can be calculated. In addition to this current and voltage measurements, the system measures the ambient temperature by using a thermocouple.

Control line-1 sets the combinations of the capacitor-modules. If the system detects a power failure in the grid line, it instantly shuts down the output of the PCS by control line-7. Using line 8, the control system sets how much power will be taken from grid line. The function of the line-12 is to set the value of load according to a pre-determined load profile. The constructions of different units of the system are given in the following subheadings.

2.1 Load Unit

In this system a resistive room heater of variable power is used as the load. The load unit consists of six resistive coils as shown in Figure.3. The coils are connected in parallel by six relays. The control system can connect or disconnect the coils by the relays. Depending on the ON/OFF states of the relays the minimum value of the load can be 50W and the maximum value can be 1150W. Within this range the value of the load can be set to any integer multiple of 50W.

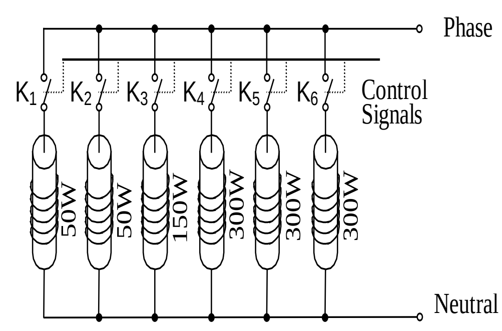

Fig 3: Construction of the load unit

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2.2 PV Panel

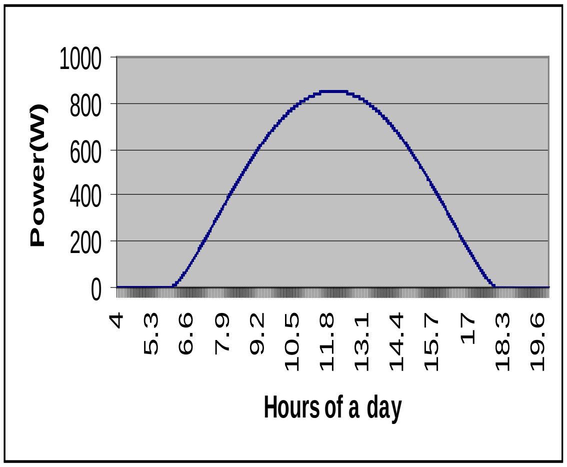

Fig 4: PV Output power on a typical sunny day

2.3 Energy Capacitor System (ECS)

In this system, Energy Capacitor System (ECS) has been used as storage device due to its various advantages .As mentioned earlier, ECS is the combination of Electric Double Layer Capacitors (EDLCs) and electronic circuits, like, parallel monitors and current pumps. To increase the storage capability and to yield a large energy output, these electronic circuits are used with the capacitors [8].

Figure 5: Photograph of the PSAP-8 EDLC

Table 1 Ratings of PSAP

Items	Capacitance (F)	Internal resist. (mΩ)	ESR (ΩF)
Minimum value	2565.0	9.8	26.2
Maximum value	2766.0	19.9	53.1
Average value	2669.0	15.5	41.3

Fig 6: Photograph of a unit of 10 PSAP-8 EDLCs and parallel monitors

The EDLC bank has been constructed using four capacitor modules. Each of the modules comprises of 36 series connected PSAP-8 type EDLCs and seven such strings in parallel. A PSAP-8 EDLC is shown in Figure 5 and its specifications are given in Table 1. Before constructing the modules, several EDLCs are connected in a PCB and the parallel monitors are connected to them as well (as shown in photograph of Figure 6). The maximum voltage of each module is 90V and capacitance is 505.5F (2600F/cap×7(no. of parallel strings)÷36(no. of series connected cap in each string)). Hence, the maximum storage capacity of the EDLC bank is 2275Wh ($^1/_2$ ×505.5×180^2/3600

2.4 Power Conversion System (PCS)

For a grid connected PV-ECS system the inverter is very important. In this work an Error Tracking Mode- Pulse Width Modulation (ETM-PWM) PCS is used. The main features of the PCS are low harmonic, bi-directional and efficient. It works as an inverter when power is supplied to the load from the ECS and the PV panel, and works as a charger when power is bought from grid line to charge the ECS. The DC input/output range of the PCS unit is 90-180V and AC input/output range is 90-110V, 50Hz/60Hz.

A simplified block diagram of the PCS is shown in Figure 7. The microprocessor controls the driver stage and this stage drives the MOSFETs. The microprocessor takes *sin ωt* signal from the grid line to synchronize the output of the PCS with the grid line voltage. The control signals V_{DC}, i_{DC}, i_{Lp} are used to control the output AC and DC voltages. The PCS acts as a boost up converter while used in charging mode and as a buck type converter while used in inverter mode. When works as an inverter, first the μP (microprocessor) sends signals at points U

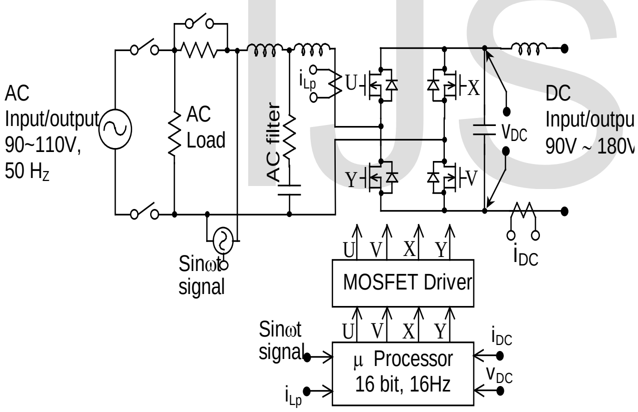

Fig 7: Simplified schematic diagram of the PCS

and V. So, the corresponding MOSFETs become ON and current flows down words through the AC load. After a certain time interval, MOSFETs X and Y become ON and current flows in the reverse direction through the load. When works as a charger, during the positive half cycle of AC, MOSFETs U and V become ON and during the negative half cycle MOSFETs X and Y become ON.

2.5 Maximum Power Point Tracker (MPPT)

The I-V characteristics of a PV panel do not match with most of the practical loads. So, to extract the maximum power from the PV panel generally a Maximum Power Point Tracker (MPPT) is necessarily used. The MPPT always matches the dynamic impedance of the PV panel with the fixed load resistance.

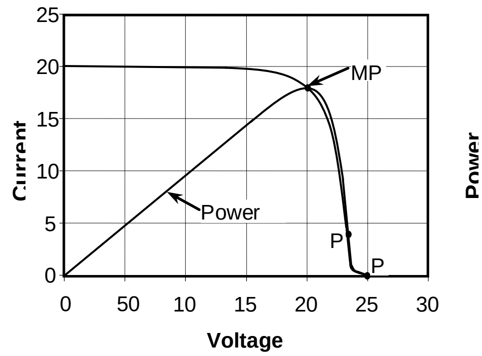

Fig 8: I-V characteristics curve of a typical PV panel

In our system a microprocessor based MPPT has been used. It has an efficiency of 95% and capacity 1000W.

2.5.1 Operation of the MPPT

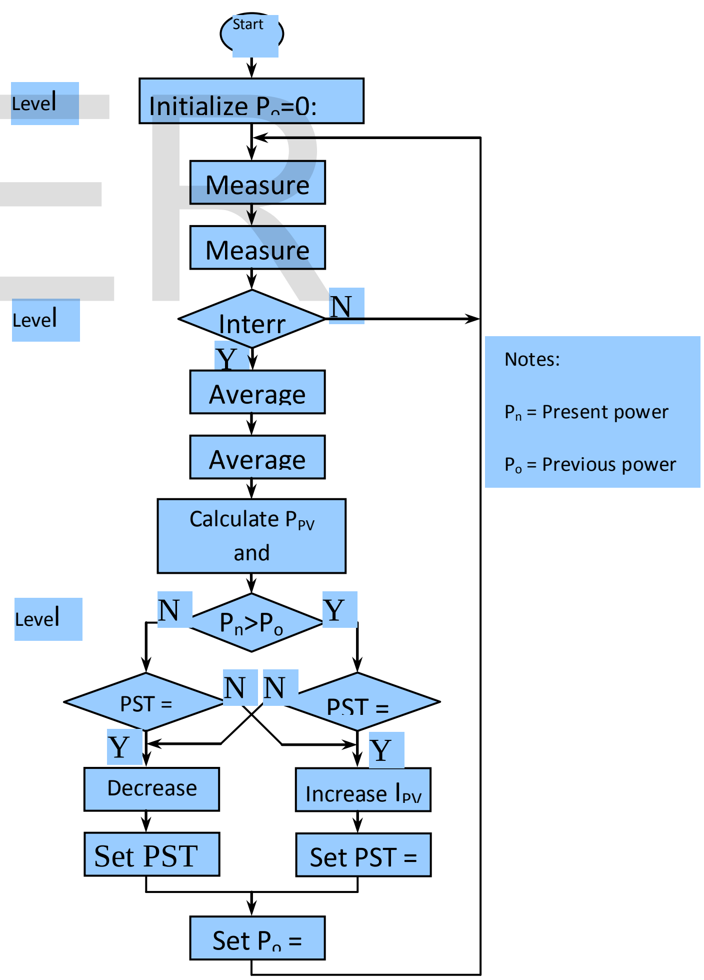

Fig 9: Flowchart of the principle of operation of the MPPT

3 Principle of Operation of the System

In the graph of Figure 10, the power flow pattern in our system on a typical sunny day is shown. Here, the "buy power" (P_{buy}), i.e., power taken from the grid line, the PV

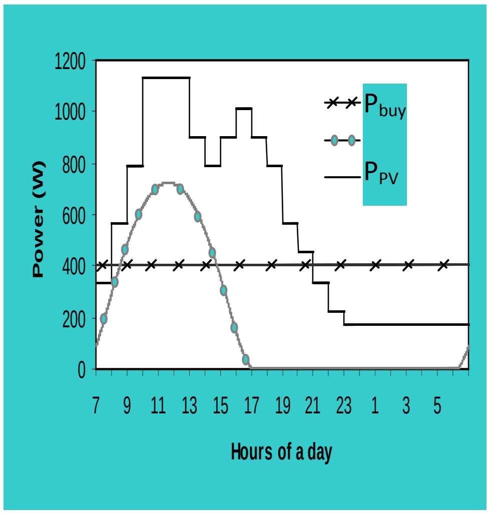

Fig 10: A typical power pattern in the system on a sunny day

power (P_{PV}) and the load power (P_{load}) have been shown. Every day the system starts at 7am and during 7:00~17:00 power is generated by the PV panel. This PV power and a preset amount of "buy power" meet the load demand. Also, when the PV output is low the EDLC power is used in addition to the "buy power" and PV power. During about 17:00~21:00, no power is generated by the PV panel so the EDLC power and the preset amount of "buy power" meet the load demand. During the time interval 21:00~7:00, although the load demand is very low, the system takes the same amount of power from grid line. The extra power is used to charge the EDLC. In this way, the system performs the function of load leveling by taking always the same amount of power from grid line. In addition to this load leveling, the system provides economic benefit by generating power by the PV panel and using the cheaper power of the EDLC during peak hours instead of costly one

4 Conclusion

The construction of the system has been described in this chapter. All of the system units have been described briefly. The full schematic diagrams of them are not given here, as they are very large. When the system will be used by the consumers, the load unit and the computer will not be necessary. Then, the whole controlling system will be replaced by a small unit, where a small microprocessor and an EPROM will replace the computer. The household appliance of the user will work as the load. Again, many measuring instrument can be excluded then.

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