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Design of Residential Grid-Tied Photovoltaic System with New Controlling Technique Under Indian Net Metering Law

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Abstract: ***The depletion of fossil-fuel resources on a worldwide basis has necessitated an urgent search for substitute energy sources to meet up the present day demand. Solar energy is clean, inexhaustible and environment-friendly resource among all renewable energy options [1]. But neither a standalone solar photovoltaic (PV) system nor a wind energy system can provide a continuous supply of energy due to seasonal and periodic weather variations. Therefore, in order to satisfy the load demand, grid connected energy systems are now being implemented, that combines solar and utility grid [2]. In this paper, a grid tied photovoltaic system was developed by omitting the energy storage device like large capacity battery bank. It will not only reduce the internal losses for charging and discharging of battery bank but also cost of the system. So, the system maintenance cost has been reduced. Here we proposed a new approach to design a photovoltaic (PV) grid-tied system, which can be operated by feeding the solar power to the national grid along with the residential load [3]. Again, if there is an extra power demand for residential load along with the solar power then this system can also provide an opportunity to consume the power from the utility grid. If the power consumption by the residential user is zero watts, then the entire generated solar power is fed to the national grid. Also, an overview of Indian net metering mechanism for renewable energy sources for power generation systems was carried out in this paper. By the proposed design and control mechanism, efficiency of the photovoltaic system was increased. In India, the proposed limit for commercial settlement of electricity is generation as 95% of the total consumption in a financial year [6]. Any excess injection of power to the utility grid, at the end of financial year to be considered as free energy. So, for that reason we have to install the photovoltaic (PV) power system that is equal/less than the total load of the residential user. By this proposed design, no worries about high power bills and also we get the invested money back in short span of time.***

Keywords: Net metering, Grid-Tied system, financial payback period, controlling technique, relay circuit.

1. Introduction

Energy plays a vital role in our daily activities. The degree of development and civilization of a country is measured by the amount of utilization of energy by human beings. Energy demand is increasing day by day due to increase in population, urbanization and industrialization [2]. The rate of energy consumption increasing, supply is depleting, resulting in inflation and energy shortage. This is called energy crisis. Energy crisis is the biggest problem for economical development of any country. Due to the rising cost and depleting storage of fossil fuels along with the increasing concern for global climate change, utilization of renewable energy in national scale has become essential for the world. The only way to save the fossil fuels like Natural Gas, Oil, Coal etc are in small scale use of those sources [4]. Hence alternate or renewable sources of energy have to be developed to meet future energy requirement.

PV systems are usually used in three main fields:
1) Satellite applications, where the solar modules provide power to satellites,
2) Off-grid applications, where solar arrays are used to
3) Power remote loads that are not connected to the utility grid, and
4) On-grid or grid connected applications, in which solar arrays are used to supply energy to local loads as well as to the utility grid.

This paper presents an improved and cost efficient way to synchronize the PV array output with the utility grid using a special and economical control scheme. So that, an individual solar PV system owner can acts as an electricity supplier to the utility grid. India is currently witnessing a transition in its solar market. Distributed solar photovoltaic's (PV) is expected to witness significant growth in India owing to increasing economic viability and a facilitating policy regulatory framework in most states. Distributed Generation (DG) can provide various system benefits in terms of improved grid reliability and power quality, deferring grid investments, reduction in transmission and distribution losses, etc. Beside environmental advantages, energy independence can be accessed by providing feasible incentives and net metering programs, which is a result of sharing extra energy and compensating customers in demand reduction.

2. Literature Survey

1. Yann Riffonneau, Seddik Bacha, Franck Barruel, and Stephane Ploix presented an optimal power management mechanism for grid connected photovoltaic (PV) system with storage. To help intensive penetration of Photovoltaic (PV) production into the grid by proposing peak shaving service at the lowest cost. The structure of a power supervisor based optimal predictive power scheduling algorithm is proposed. Optimization was performed using Dynamic Programming (DP) and was compared with a simple ruled-based management. They

points out that peak shaving is realized with the minimal cost, but especially that power fluctuations on the grid are reduced which matches with the initial objective of helping PV penetration into the grid [1].

2. S.B. Kjaer, J.K. Pedersen, F. Blaabjerg focuses on inverter technologies for connecting photovoltaic (PV) arrays to a single-phase grid. The inverters are categorized into four classifications: a) the number of power processing stages in cascade, b) the type of power decoupling between the PV module(s) and the single-phase grid, c) whether they utilizes a transformer (either line or high frequency) or not; and d) the type of grid-connected power stage. Various inverter topologies were presented, compared and evaluated against demands, lifetime, component ratings and cost. Finally, some of the topologies are pointed out as the best candidates for either single photovoltaic (PV) arrays or multiple PV module applications [6].
3. K. Agbossou, M. Kolhe, J. Hamelin, and T. K.Bose proposed a AC-linked hybrid wind/photovoltaic (PV)/fuel cell alternative energy system for stand-alone applications. Wind and PV are the primary power sources of the system, and a fuel cell electrolyser combination is used as a backup and a long-term storage system [2].

3. Grid Connected System

Photovoltaic (PV) systems are mainly of two types,
1. Stand alone Photovoltaic systems, and
2. Grid connected Photovoltaic systems.

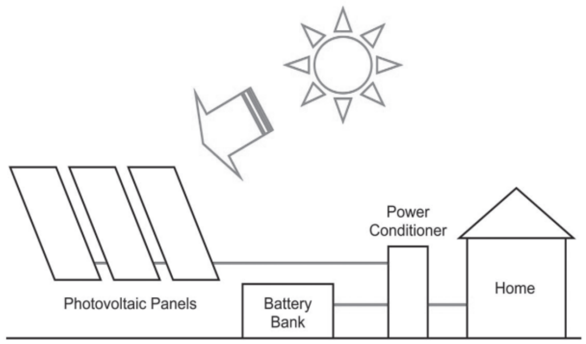

Figure 1: Stand alone Photovoltaic system

3.1 Existing system

In existing system power is stored in battery using charge controller and when utility power fails, load runs on the battery power. A typical grid connected system is shown in fig.2. In this, photovoltaic system generated power is stored in the battery and when needed it supplied to the loads by using the inverter.

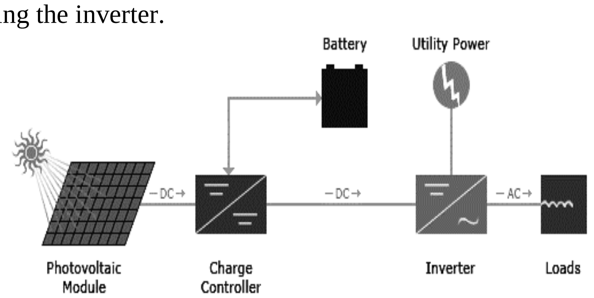

Figure 2: Grid connected Photovoltaic system

3.2. Proposed System

There are losses present in charging and discharging of the batteries. For that reason, here we proposed a system that does not have storage equipment, and a new controlling technique was proposed to control the photovoltaic generated power and utility supply. We designed a controlling technique by tacking four conditions into account. Those conditions are: a) Load value is less than the photovoltaic system (day time), b) Load value is equal to the photovoltaic system (night time), c) Load Value is more than the photovoltaic system (day time), and d) Load value is almost equal to zero (day time).

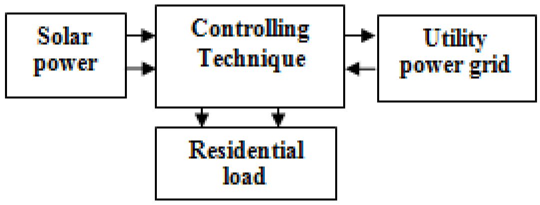

Figure 3: Layout diagram of the planned grid-tied PV system

In first condition residential load uses the photovoltaic generated power and the excess PV power is fed to the utility power grid. In second condition, residential load uses the utility grid power. In third condition, residential load uses both photovoltaic (PV) system power and utility grid power. And, in the last condition the power generated by photovoltaic system is fed to the utility source, here residential load is almost zero.

4. System Description

For any renewable energy plant, storage system costs nearly 30 per cent in the total cost of the system. So, cost of the renewable energy system is high. Here we proposed a PV system that works without storage, by that we can able to reduce cost of the system.

Relay circuit is used to control which to operate and which not to operate. Here we designed a relay circuit by using three relays. The voltage obtained by the photovoltaic system is boosted by using a DC-DC boost circuit. The booster circuit boosts the output voltage to 40Volts. The output of booster circuit is connected to inverter. Here we designed a inverter that is having best islanding effect. Relay control circuit is shown in fig 4, and which is used to control the total system. Islanding is defined as the condition in which a distributed generator continues to power a location even though electrical utility is no longer present [2].

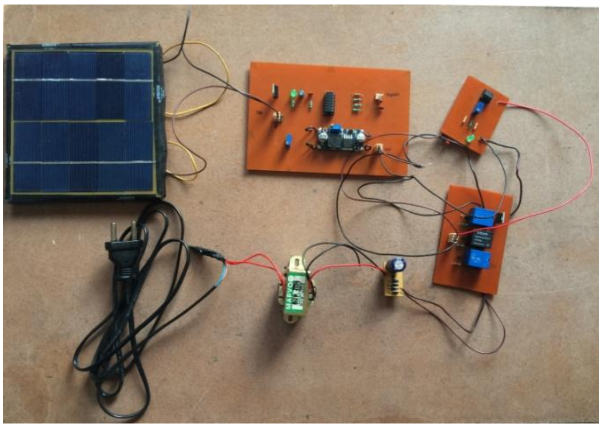

Figure 4: Prototype design for the proposed system

Solar irradiation is typically provided as kWh/m^2. However, it can be stated as daily peak Sun hours. This is the equivalent number of hours of solar irradiance of 1 kW/m^2. The grid interactive roof top solar PV system comprises the following equipment.

a) Solar PV Power Source, b) DC-DC converter, c) Inverter,
d) Mounting Structure, e) Power and control Cables,
f) Earthing equipment /material,
g) Junction Boxes or combiners, and
h) Instruments and protection equipments

a) Solar PV Power source, photovoltaic solar system use the light available from the sun to generate electricity and feed this into the utility electricity grid or load as the case may be. The photovoltaic (PV) panels convert the light reaching them into DC power. The amount of power they produce is roughly proportional to the intensity and the angle of the light reaching those. They are therefore positioned to take maximum advantage of available sunlight within the siting constraints. Maximum power is obtained when the PV panels are able to 'track' the sun's movements during the day and the various seasons. However, these tracking mechanisms tend to add a fair bit to the cost of the system, so a most of installations either have fixed PV panels or compromise by incorporating some limited manual adjustments, which take into account the different 'elevations' of the sun at various times of the year. The best elevations vary with the latitude of the load location.
Current and voltage relationship of a PV cell is given by

$$j_i = j_o\left[exp\left(\frac{V_e}{KT}\right) - 1\right] \quad (1)$$

Where,

j_o is the saturation current also called the dark current
v is the voltage across junction
e is the electronic charge
k is Boltzmenn's constant
T is the absolute temperature

b) DC-DC converter, which converts the lower dc voltage to high dc voltage. For this purpose boost converter is used.

c) Inverter, DC power produced is fed to inverter for conversion into AC. In a grid interactive system AC power is fed to the grid at 11 KV three phase systems or to a 415V three phases or to a 220/240 V single phase system line depending on the system installed at institution/commercial establishment or residential complex or single house consumer and load requirement. Power generated from the PV system during the daytime is utilized fully by powering the captive loads and feeding excess power to the grid as long as grid is available. In cases, where the solar power is not sufficient due to cloud cover etc. the captive loads are served by drawing power from the grid. The inverter should always give preference to the Solar Power and will use Grid/DG power only when the PV Power is insufficient to meet the load requirement.

d) Mounting structures, hot dip galvanized iron mounting structures are used for mounting the modules/ panels/arrays. These mounting structures must be suitable to mount the Solar PV modules/panels/arrays on the roof top, on the ground or on the poles/masts, at an angle of tilt with the horizontal in accordance with the latitude of the place of installation.

e) Power and control cables, the cables shall be 1.1 grade, heavy duty, stranded copper/aluminium conductor, PVC type-A insulated, galvanized steel wire/strip armoured, flame retardant low smoke (FRLS) extruded PVC type ST-1 outer sheathed. The cables shall be in general conform to IS-1554 P+I & other relevant standards.

f) Earthing equipment, earthing is essential for the protection of the equipment &manpower. The system earth is earth which is used to ground one leg of the circuit. For example in the AC circuits the Neutral is earthed while in DC supply +ve is earthed.

4.1. Control Section

The power measuring block measures the solar power with respect to the time. The AC current sensor senses the residential load current which can be converted into power by multiply with the system voltage. The output of the measured solar power and the load demand goes to the controller.

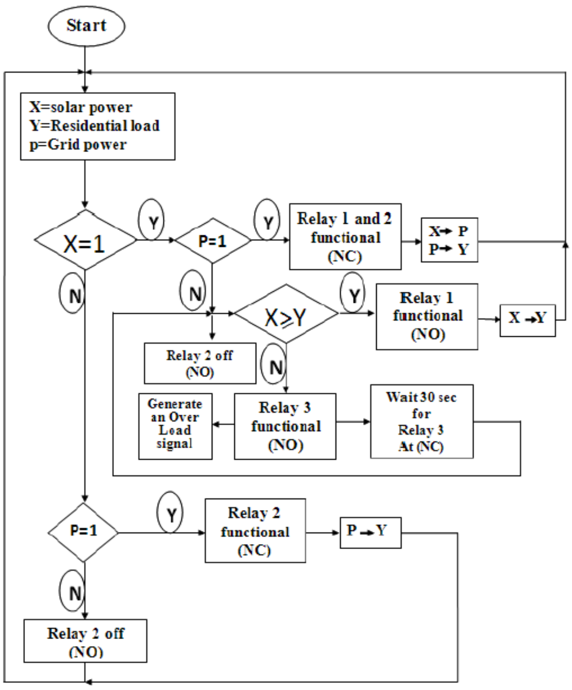

Figure 5: Flow Chart for relay control

The availability of the grid power can be detected by a power transformer. The output of the PT goes to the controller through ADC. With the help of these data controller will send signal to the relay control circuit. Then the relays will operate according to the decision of the controller. The relay control circuit consists of a 10kΩ resistance and a NPN Transistor (BC547). Fig.5 shows the relay control circuit. Relay is an electrically operated switch. Relays are used to control a circuit by a low power signal (with complete isolation between the circuits), or where several circuits must be controlled by a signal. Normally open (NO) contact connects the circuit when the relay is activated and Normally closed (NC) contacts disconnect the circuit when the relay is activated.

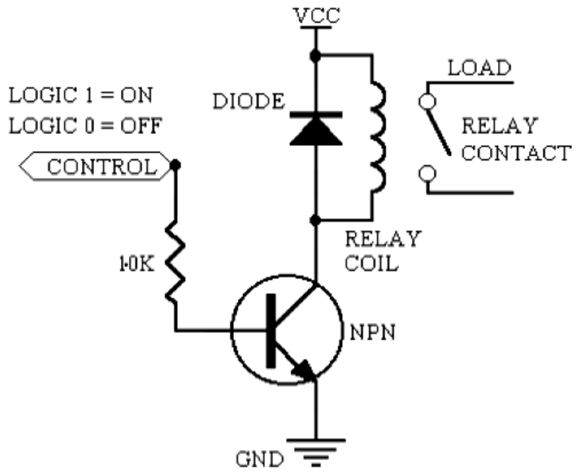

Figure 6: Relay control circuit

4.2. Net metering

There are two different types of metering arrangements that can be used for development of rooftop solar photovoltaic (PV) systems: gross and net metering. Net metering is a service to an electric consumer under which electric energy generated by the electric consumer from an eligible on-site generating facility and delivered to the local distribution facilities, may be used to offset electric energy provided by the electric utility to the electric consumer during the applicable billing period. Government of India launched the Jawaharlal Nehru National Solar Mission (JNNSM) in 2009 to increase share of solar energy. As of June 2015 ten states in India (Gujarat, Andhra Pradesh, Uttarakhand, Tamil Nadu, West Bengal, Karnataka, Kerala, Delhi, Punjab, Telangana) have released a final distributed solar or net metering policy regulatory framework.

Indian Net-metering Guidelines

1) Proposed limit for commercial settlement of electricity generation as 90% of the total consumption in a financial year.
2) Excess injection (above 90%) at the end of financial year to be considered as free energy.
3) No carry forward of energy allowed to next financial year.
4) Table.1 shows the reference case for energy accounting under Indian net metering.

Table 1: Energy accounting under Indian net metering

Month	*Generation*	*Consumption*	*Net Electricity*	*Effective Bill*
April	150	160	10	10
May	150	180	30	30
June	150	20	-130	-130
July	150	260	110	-20
Aug	150	100	-50	-70
Sep	150	160	110	40
Oct	150	140	-50	-10
Nov	150	200	50	40
Dec	150	220	70	70
Jan	150	100	-50	-50
Feb	150	200	50	0
Mar	150	0	-150	-150
Total	1800	1840	40	40

4.3. Cost and Area requirement

The average potential roof-space requirement for a typical 1 KWp solar PV power plant will be 80 sq-ft (approx) shade-free area and similarly proportionately higher area for higher capacity system. The tentative cost of grid-interactive 1 KWp rooftop solar PV plant will be Rs. 1.1 to Rs 1.3 lacs (approx). Similarly, 1 KWp off-grid system with minimum battery back-up shall require Rs. 1.5 lacs to 1.7 Lacs (approx). In addition that all such systems, 30% subsidy shall be availed from Ministry of New and Renewable Energy (MNRE) Government of India, through state nodal agencies.

4.4. Advantages of the designed system

A typical solar system would require a large battery bank to storage the energy. By removing this storage device the system installation cost can be maintained within an acceptable limit. The grid connected system is more power efficient than a conventional solar system. It ensures full utilization of solar energy whereas battery discharge rate is 65% to 70% in conventional off-grid solar system. As energy storage capacity of these batteries degrade with time, and need replacement, which required extra cost for the system owner. This grid-tied system also represents the consumer as an energy provider to the utility grid. Net metering allows system owners to get credit for any electricity from the system sends to the utility grid. If the grid power is not available, still the system will continue to supply critical on-site loads.

5. Results

The grid tied solar photovoltaic (PV) system was successful implemented. When there is availability of solar power, the corresponding relay was switched ON and the residential load consumes power from it. When the residential load is absent and there is availability of solar power, then corresponding relay was switched ON and the solar power supplied to the utility grid. When solar power was absent, then the residential load consumes utility grid power.

6. Conclusion and Discussions

In this paper an advanced grid-tied PV system with relay controls technique was shown, which is suitable to produce more energy from renewable energy sources. Impact of net metering on cost and saving according to different state policies in India are studied. It has been concluded that cost of the system was minimised compared to the cost of existing grid connected photovoltaic system with storage. Losses of the photovoltaic grid tied system were reduced to minimum level. By the proposed method, residential user can be able to use power at any time without interruption. Maintenance of the system was minimised.

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