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Paper Authors

K.SHALINI, P.SADANANDAM

VAAGDEVI COLLEGE OF ENGINEERING

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MODELLING AND SIMULATION OF INTELLIGENT GRID INTERFACED SOLAR WATER PUMPING SYSTEM.

[1]K.SHALINI, [2]P.SADANANDAM
[1]Dept of EEE, VAAGDEVI COLLEGE OF ENGINEERING
[2]Dept of EEE, VAAGDEVI COLLEGE OF ENGINEERING

ABSTRACT

The paper presents development of a utility interface solar power converter to supplement deficit in Grid power supply for a water pumping system used in rural home of Indian villages. The power supply system comprises of solar (PV) array, PWM converter incorporating PWM control strategy, energy storage battery devices, submersible pump and water storage tank(s) etc. The model of the system has been designed for its optimal operation and a prototype solar power converter unit has been developed to drive a ½ hp pump motor. The Life cycle cost evaluation of the solar power converter has been done and compared with conventional DG set. This has resulted in a cost effective system with a 60% - 70% grid power saving.

Keywords: Photovoltaic; solar pump; PWM inverter; Diesel Generator

1. INTRODUCTION

Water is the basic need of all living being. Approximately 30% of world population lack access to water for drinking, livestock and irrigation. Traditional technology used to access the water from available sources like bore well or open well employ water pump to lift water and store it in an overhead tank(s). These pumps are either powered by conventional grid supply or alternative Diesel Generating (DG) set etc. but higher cost of fuel consumed by DG set and non availability of adequate grid supply have forced scientist and engineer to think for either a supplementary or alternative renewable energy source to produce electrical power[1,2,3,4,5,6,]. Solar photovoltaic energy is one of the potential source is preferred due to availability of free sun fuel ,straight forward technology, lower maintenance with reliable operation etc. Though the solar modules (cells) are expensive but efforts are being made to use it not only for power conversion but also for building the exterior wall or covering the roof of pump farm houses or water pump Houses. Further, the demand of electricity is increasing day by day by the growing population where as grid supply extension has almost become standstill due to its limited resources like fossil fuel etc. and its further expansion is not possible due to various technical and economic reasons. This has motivated the researchers to develop utility interface solar power converter to generate power which can meet the increasing energy demand of houses

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located specially in rural sector of the country connected to weak grid supply sources. The system can work even as a standalone device in the grid less village areas. Data acquisition of demand based load profile were accessed .The computational analysis for optimal design of the component has been done and prototype Inverter model has been developed and tested for its dynamic Performance. The proposed system is able to bring an energy saving up to a maximum value of 60-80% of power drawn from utility supply in these rural houses. The modeling and design of components of water pumping system include the following modules

- PV cell
- Battery back-up source
- PWM Inverter
- Intelligent power controller
- Pump for water storage in an overhead tank etc.

The present study highlights the following:

- Study of user demand of pump and lightening load profile in a rural house of Indian villages
- Optimal design of solar power converter module consisting of PV array, Battery, PWM Inverter and PumpMotor etc. • Prototype development of utility interface solar adaptive Power converter unit.
- Life Cycle Cost Analysis of the prototype solar converter system and its cost comparison with DG set.
- Social Impact of use of solar powered converter on rural development in Indian Villages.

- The solar energy is harnessed through photovoltaic cell and converted into utility grade AC power using PWM inverter. The system adapts to meet the varying load profile under two modes of its operation. The schematic diagram of the proposed scheme is shown on Figure (1).

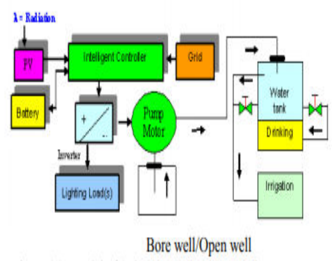

Figure (1): Model of Solar Power Converter and Pump Motor

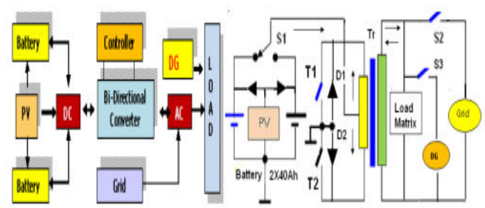

Figure (2): Block and Circuit Model of utility interface Solar Power Converter System

The converter works in bidirectional mode and performs both under charging and inverter mode of operation. The push pull configured centre tapped converter unit is switched ON and OFF alternatively in push pull mode by transistorized switching Power devices to produce ac power from the DC source.

Mode 1: High Insolation / low Insolation with more than 50% state of charge (SOC) of the Battery : The PV charges the battery bank as well as feed lighting load through PWM inverter.(S2 remain ON)

Mode 2: Low battery condition (less than 50% SOC) : Grid or DG (in absence of Grid) is connected to

- load and charges the Battery till it becomes fully charged (S1 or S3 become

ON) The switching of these power devices are controlled through PWM base drive pulses and thus minimizes the power loss. The intelligent controllers monitor and control the system parameters and perform the various power management control tasks like:

- PV power management
- Battery management
- Load power management

2. OPTIMAL DESIGN OF SYSTEM COMPONENTS

2.1 PV Sizing

The empirical formula based on energy balance equation has been used to compute the optimal size of PV module for critical limit of load as stated below:

$$\text{PV Cellrating} = \frac{P_{avg}}{\text{SunHour} * \text{S.F}} \quad (1)$$

(Where sun hour = 6.2 for area under study, S.F. = 1.2 for cloudy weather)

$$P_{avg} = \sum_{0hr}^{24hr} P_L / 24hrs \quad (2)$$

The average load power (P_{avg}) is computed over 24 hrs taking the load value as constant for every 1 hour interval.

$$\text{The optimal number of PV module} = \frac{\text{PV Rating}}{\text{Standard PV Module}} \quad (3)$$

2.2 Battery Sizing

Battery stores the energy to a maximum value as per average load power requirement.

$$\text{The battery capacity} = \frac{\text{Average Load Power}}{12V * SOC} \quad (4)$$

Where SOC (State of Charge) of Battery = 50%

2.3 Pump Motor

The pump is driven by ac motor whose optimal value can be computed by the following expression

$$\text{Motor Power} = \frac{H_p}{\eta} \quad (5)$$

Where H_p = Hydraulic power of pump [W]

η = Efficiency of pump

The hydraulic power H_p can be computed by the following expression

$$H_p = Q \rho g H \quad (6)$$

Where, Q = discharge rate, ρ = density of water 1000kg/m^3, g = acceleration due to gravity 9.81 m/s^2, H = dynamic Head (m)

2.4 Inverter Module

The inverter produces AC power output with DC power input .The efficiency of Inverter depends on harmonic content in ac output power which depends on the number of PWM switching pulses i.e. N approximated to a sine wave in both the half cycle of output AC wave. The PWM pulses are generated through Microprocessor/computer software program embedded in single chip of integrated circuit.

3. PWM CONTROL ALGORITHM OF PV CONVERTER

The PV converter produces PWM sinusoidal pulses using Direct PWM modulation control strategy. The pulse width (Pi) of PWM pulses approximating to an equivalent sine wave is computed from the control algorithm (equation 7) as stated below:

$$P_i = \frac{180}{2N} 2 * \text{Sin}\,(2i-1)\,\pi/_{2N} \quad (7)$$

Where, P_i = PWM pulse width of i_{th} pulses

N = number of PWM Pulses within one half cycle approximating to a sine wave

i = 1, 2....N

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The simulated PWM pulses for a typical representative value of N=3 is shown on Figure (3).

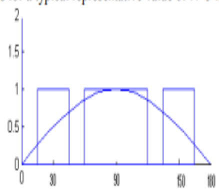

Figure (3): Simulated Direct modulated Sinusoidal PWM pulses for N = 3 in one half cycles (10ms=180 Deg), Frequency = 50 Hz (Scale X = Degree; Y= Pulse Voltage x 5V)

4. HARDWARE IMPLEMENTATION

The algorithm of software program for generation of N number of PWM pulses has been implemented through 16 bit Microprocessor (8086). The pulse width and Notch width timings are computed from the switching angles of PWM pulses and are loaded in the timer (peripheral device) unit of Microprocessor and outputted through ports interfaced with Microprocessor. The programs flow-chart (Figure (4)) is as depicted below:

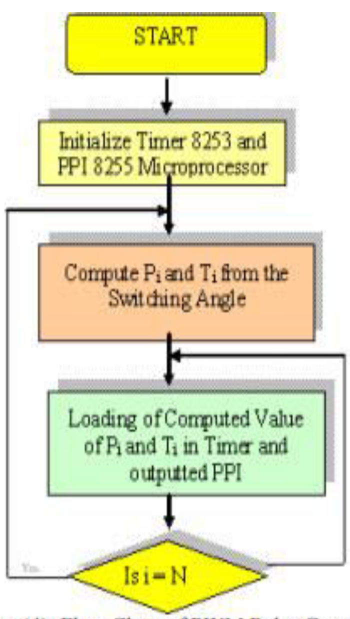

Figure (4): Flow Chart of PWM Pulse Generation Program

5. TECHNICAL SPECIFICATION

A prototype solar converter unit of the system has been designed and developed as depicted in Table (1).

Table (1): Technical Specification of Prototype Sample of Solar Converter system

PV Cell	12V, 75Wp @ STP
Battery (Lead Acid)	12V, 150Ah
PWM Inverter	500VA, 220V, 50Hz PWM Sine Wave
Load	Pump (Self priming ¼ HP submersible pump for dynamic head of 10 meters ,CFL etc.
Grid Power	220V ±10%, 50Hz
Duty Ratio	User Demand

6. POWER FLOW CONTROL ALGORITHM

The adaptive model of Load Power flow control system is governed by following expression (equation 8). The Power flow control algorithm is shown in Table (2).

$$P_L = P_{PV} \pm P_{BAT} + P_{GRID} \quad (8)$$

Where, P_L = Load Power [w]
P_{BAT} = Battery Power [w]
P_{GRID} = Grid rectified DC power [w]
P_{PV} = PV Power [w]

Table (2): Load power flow integration

Energy Source	Grid	PV	Battery	Load
Power Status of Energy Source	0	0	0 (-)	(-)
	0	1	1 (+)	(+)
	1	0	0 (-)	(+)
	1	1	0 (-)	(+)

7. ADAPTIVE POWER FLOW AND CONTROL STABILITY OF THE SYSTEM

The system response time for switching the load has been modeled with an overshoot and undershoots limited up to 1.5% and settling time of 1second. The Digital Logic Adaptive Controller (ADLC) integrate the Power sources to meet the demand based Loads and give a constant output power (Fig.5)

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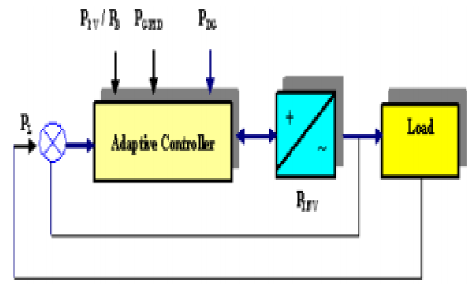

Figure (5): Adaptive power flow and Control Stability of Solar converter

8. EXPERIMENTAL OBSERVATIONS AND INVESTIGATION

PV Radiation Data Acquisition

The solar power radiation data acquired during Sun hour Period from PV module of 75Wp is recorded under Table (3) as follows:

Table (3): Solar Radiation Data (Power Output) of solar cell acquired during Sun Hour Period

Time (AM)	6	7	8	9	10	11
Power [W]	0	5	50	60	70	75
Time (PM)	12	1	2	3	4	5
Power [W]	78	65	60	55	10	0

9. LOAD POWER PROFILE

The demand base peak load power of a Farm House (lighting and pump motor) profile encountered by the

system has been recorded in Table (4) The users fix up priority to switch ON lighting loads connected at various locations of farm house and also the operating time and its duration for Pump loads.

Table (4): Peak Load Power Demand Profile of A Rural house for a typical day (24Hour) recorded in the month of Dec 2009

Hour	Load Power[w]	Hour	Load Power[w]
1	10	13	-
2	10	14	-
3	10	15	10
4	10	16	10
5	10	17	10
6	200	18	300
7	300	19	200
8	-	20	20
9	30	21	30
10	-	22	20
11	-	23	10
12	-	24	10

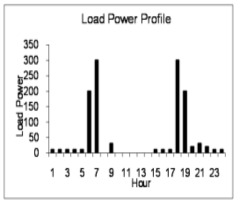

Figure (6): Load Profile

10. COMPUTATIONAL DESIGN ANALYSIS

The system component parameters i.e. PV sizing, Battery sizing etc were designed for a proto type sample having the following specification

Load Profile = 1200 -1800 watt-hour over 24 Hour

PV size = 75 Wp, 12V

Battery Size = 150 Ah, 12V Lead Acid tubular Battery Inverter grade

Pump Motor = 1/2 hp, self priming, dynamic head 10-15 meter, 3x1000 liter Tank

Inverter = 300VA/500VA, 220V, PWM sine-wave 50Hz

11. PERFORMANCE OF SYSTEM

The Peak load power as depicted in Table (4) has been simulated at laboratory. The test were carried out on prototype sample (Fig.7) at loads over the period of 24 Hours and found satisfactory.

Figure (7): Prototype Sample of Utility interface Adaptive Solar Power converter

12. LOAD WAVEFORM

The image of PWM base drive pulses and load waveform on oscilloscope were shown in Fig. (8).

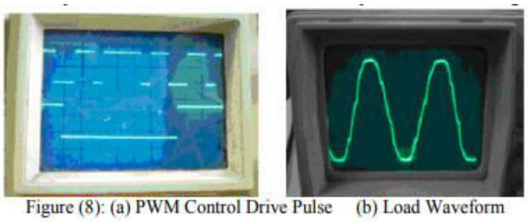

Figure (8): (a) PWM Control Drive Pulse (b) Load Waveform

13. HARMONIC ANALYSIS

The harmonic content of the PWM pulses for different value of N number of pulses is computed using MATLAB program as a Total Harmonic distortion (THD) up to nth Harmonic (restricted up to 15th harmonic) as shown in Table (5)

Table (5): Harmonic Analysis THD Computation for Different value of PWM pulse (N= 1...9) In a half cycle of sine wave Up to 15 th harmonics terms (n)

n / N	n=3	n=5	n=7	n=9	n=11	n=13	n=15
N=1	0.3333	0.38873	0.41415	0.42879	0.43833	0.44502	0.44999
N=3	0.18196	0.32707	0.33599	0.33129	0.33204	0.42257	0.4422
N=5	0.035439	0.035909	0.15388	0.32554	0.33816	0.40516	0.4382
N=7	0.018487	0.018487	0.018487	0.019893	0.17297	0.30796	0.32895
N=9	0.011272	0.011275	0.011275	0.011275	0.011276	0.015853	0.018371

14. EFFICIENCY OF CONVERTER

The Efficiency of the solar converter has been observed as almost constant for all ranges of Load (0-300W) as shown in Figure (9).

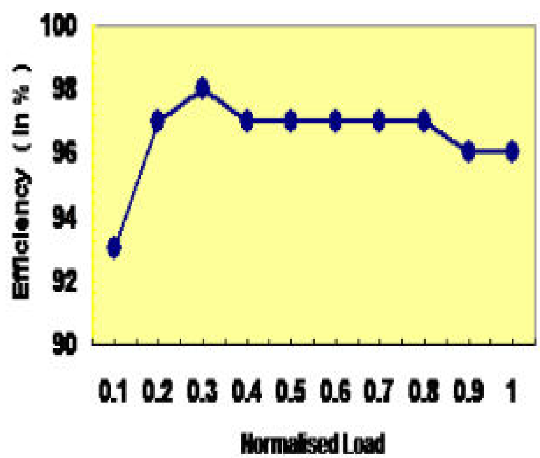

Figure (9): Efficiency of inverter

15. BATTERY CHARGING

The charging takes place in the battery by the solar power as well as from the utility supply during sun hour period and night hours respectively under two mode of its operation

- Bulk charging mode (high current): High insolation condition .The terminal voltage of Battery is set as 2.5 -2.7V.
- Trickle Mode (Under low Insolation condition). The terminal voltage is set as 2.2V - 2.35 V. The charging current drawn by Battery and the status of Battery terminal voltage is recorded as depicted in Fig. 10

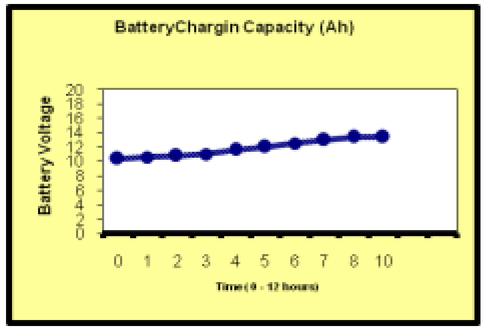

Figure (10): Charging Current of Battery

16. CONCLUSION

In this, investigations have been carried out on the development of solar power converter as an alternative or supplementary source to conventional grid for agriculture and household applications for rural masses in Indian villages. The following features have been included in the system

- The technology used in the proposed scheme is simple, cost effective and having fast response in terms of
control stability under varying solar radiation and/or agriculture load conditions.
- The system can be scaled to higher rating easily. It is easily maintainable and confirm to sinusoidal quality with low switching loss with very less harmonic content.
- The load power adaptability feature of inverter and PWM control strategy offer almost constant efficiency with high value

(more than 90%) and less THD value (3%or even less)irrespective of varying level of load demand(s) and/or solar insolation. PV solar converter

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