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A MAXIMUM POWER POINT TRACKER FOR A PV COMPONENT OF A WIND/PHOTOVOLTAIC/FUEL CELL DISTRIBUTED GENERATION POWER SYSTEM

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ABSTRACT
In this paper, a maximum power point tracker (MPPT) is developed for the photovoltaic(PV) arrays in a power distribution system composed of wind /PV/fuel fell. The MPPT is a step-down DC-DC converter connected to the 2.5 kW PV array which is in turn connected to a 24V deep discharge battery bank. Also an inverter for the AC load is installed for grid interactive operation. The MPPT uses power MOSFETs controlled by an external logic signal circuit for switching. The logic signal uses PWM technique to control the duty cycle at frequency of 52 kHz for extracting the maximum power at any irradiance. As a result of that, the MPPT has improved PV output power for different irradiance. The efficiency of the MPPT is high.

KEY WORDS
Maximum power Point, photovoltaic

I. Introduction

The distributed generation power system (DGS) wind/PV/fuel cell is installed at the Ball Hall building at the University of Massachusetts, Lowell. The power system can be described as the follow;

Wind Turbines

Three wind turbines, the 1.5kW, 500W, and 300W wind turbines, are installed on the roof of the Ball Hall Building. A Bergery 1.5kW is at 80 feet above the ground while a World Power Technologies Mariner 500 and a Southwest Wind Power Air Marine 300 are both at a height of 14 feet above the roof. The power of the wind turbines depends on the wind speed. The wind turbines have permanent magnet generators that generate power at variable frequency. The wind turbine generates peak power in fall and winter and during the day between 3-6 pm in the region of Lowell[1]. The generated power then is rectified to 24V and fed to the battery bank.

Photovoltaic

A 2.5 kW photovoltaic array is made of 70 Acro modules installed on the roof next to the wind turbines. The photovoltaic cells are connected to form 3 arrays; 2 arrays of 25 modules and one array of 20 modules. Each module is rated at 53W by the manufacturer. The PV array has a fixed inclination of 42 degrees. This angle corresponds to the optimum tilting in spring for the installed PV, and is the latitude of Lowell. The power also depends on temperature, wind speed and age of cells. Photovoltaic array peaks in late spring and summer from 12-3 pm.
Clearly explain the nature of the problem, previous work, purpose, and contribution of the paper.

The array voltage is stepped down to 24V through a MPPT and connected to the battery bank.

Fuel Cell

Fuel cells are the devices that convert chemical energy into electricity directly with no intermediate combustion step. A typical fuel cell consists of two electrodes, an anode and a cathode to which fuels and oxidant are fed. The electrodes are separated by a solid electrolyte layer. Fuel cells are characterized by the type of electrolyte. The fuel cell used in this work is a proton exchange membrane fuel cell (PEMFC). The PEMFC generates DC electricity from the electrochemical reaction using hydrogen and oxygen from air, only by-product of heat and water vapor. The basic chemical reaction processes are expressed as follows;

Anode side: $H_2 \Leftrightarrow 2H^+ + 2\mathbf{e}^-$
Cathode Side: $(\frac{1}{2})O_2 + 2H^+ + 2\mathbf{e}^- \Leftrightarrow H_2O$
Total Cell reaction: $H_2 + 1/2O_2 \Leftrightarrow H_2O$

The fuel cell stack, model PEM-PS500 manufacturer by HPower, provides a maximum 500W of the continuous power. PS500 fuel cell stack has the dimension of 11.5x8.5x18.5 in. and weights 35.5 lb.

PEMFC demonstrates a reliable, clean, non-polluting technology for the environment. Unlike a battery to be charge or discharge, PEMFC operate as long as fuel and air are supplied. The fuel cell has high efficiency range from 40% to 60%, three times compared with 20% generated by the conventional generators. Fuel cell is a portable, light weight power source. In addition, PS500 is safe, quiet, energy efficient and versatile [2,3,4].

Batteries

Twenty-four Trojan deep discharge batteries are installed with the capacity of 44 kWh. Four batteries are connected in series to form a 24V DC bus voltage. The excess energy is stored at favorable time and used when necessary.

Inverter

A 4Kw Trace Engineering inverter is connected between the battery bank and the utility grid at 120V AC. This microprocessor-controlled inverter delivers power to the grid.

The configuration of the DGS Wind/PV/Fuel Cell is shown in Fig.1.

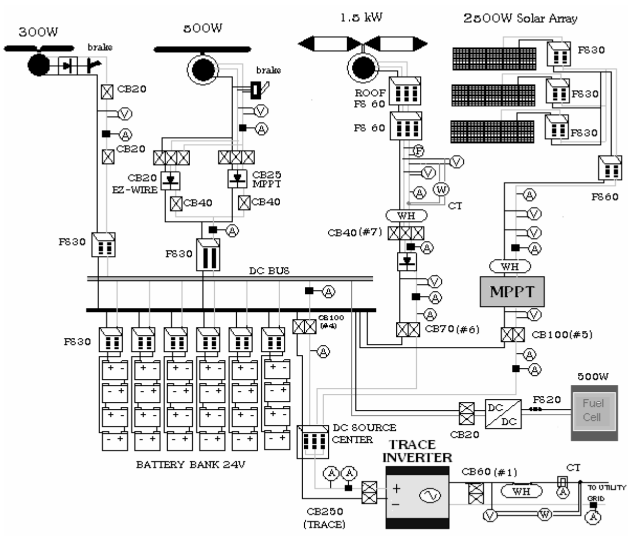

Figure1. DGS Wind/Photovoltaic/Fuel Cell System Configuration

Renewable energy has been developed all around the word for decades. One of the most interesting and successful energy sources is a PV system. A PV cell or solar cell converts sunlight directly into electricity. Because sunlight is available everywhere, this makes a PV system attractive. Unlike combustion engines using gasoline that emit noxious gasses such as carbon monoxide (CO) into environment, PV power is emission-free [5, 6]. The purpose of this paper is to present the design, performance, operation and determine the efficiency of the MPPT.

II. Maximum Power Point Tracker (MPPT) for the Photovoltaic

The PV system is described by its current-voltage characteristic under different solar irradiances as shown in Fig.2. PV performance depends on many factors such as irradiance, cell temperature, and age of the cell. When the PV array is connected directly to the load, the system's operating point is the intersection of the current-voltage (i-v) curves of the PV and the load. This point is generally not at the maximum power of the PV array. The mismatch between the PV arrays and the battery bank occurs because their performances depend adversely on temperature. MPPT is a device that sustains the PV's operating point at the maximum power output. The maximum power point line (P_{max}) demonstrates the maximum power point at any irradiance at 23 ºC for the 2.5 kW PV system shown in Fig.2. Several MPPTs use step-up (boost) or step-down (buck) choppers depending on the required output voltage from the MPPT [7-12]. The step-down chopper is selected to use as a DC-DC converter to match the PV array and the battery bank voltages [9]. The step-down DC-DC converter schematic is shown as in Figure3. The output performances taken at 23°Celsius at 900W/m^2 obtained from the manufacturer specification are as follows:

Open circuit voltage	V_{oc} = 98.0	V.
Short circuit current	I_{sc} = 35.5	A.
Current at maximum power point	I_{mp} = 31.7	A.
Voltage at maximum power point	V_{mp} = 74.0	V.

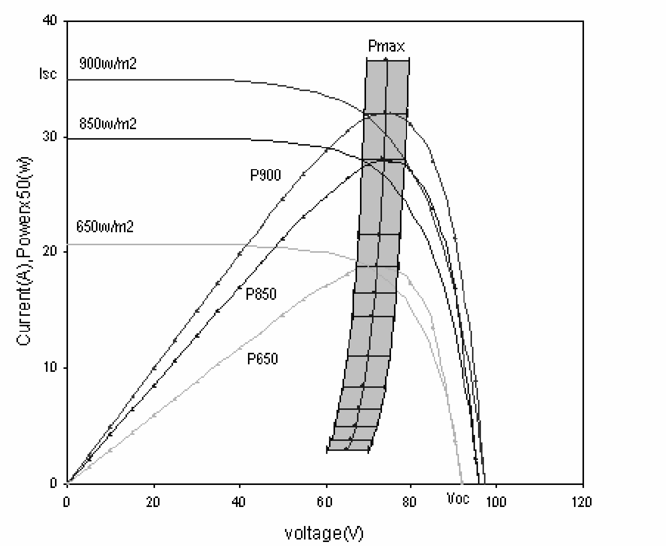

Figure2. I-V and P-V characteristics of a PV system at Constant Temperature (23°C)

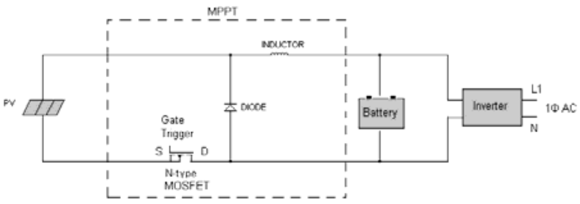

Figure3. DC-DC Converter Circuit

The maximized power from the PV array is transferred through the DC-DC converter to a 44 kWh battery bank and to the utility via a microprocessor-controlled inverter-charger manufactured by Trace Engineering.

III. MPPT Strategy and Logic Circuit

Constant voltage method is used in controlled circuit because MPPT voltage changes slightly with varying irradiance. Several algorithms can be implemented, for example perturb and observe, incremental conductance, and parasite capacitance [8,12,14,15]. The perturbation and observation methods are periodically increasing or decreasing the array voltage to approach the maximum power point. The incremental conductance methods the PV arrays voltage is adjusted relative to maximum power point voltage by comparing the incremental conductance with instantaneous array conductance. Parasite capacitance uses the switching ripple of the MPPT to perturb the PV array [16,17]. These methods require more complicated implementation in measurement, database, and complexity of calculating procedure. They require the microprocessor to operate at the high speed operation which adds cost. These algorithms are more complex or expensive for this work. In this paper the proposed MPPT is simplification and effectiveness for high power output. With constant voltage method, the MPPT is set to a fixed voltage. Frequency of 52 kHz is used to avoid audio noise in the level that humans can hear. The high frequency reduces the size of passive filtering elements and having faster response to change in behavior. In the contrary, it has higher switching losses and radiated EMI which interfere with nearby power electronic circuits.

The step-down DC-DC converter is chosen because the required output voltage is less than input voltage from the PV. This MPPT uses power MOSFETs to convert the PV array voltage to 24V for a battery bank. MOSFETs are selected because of their high efficiency and fast switching ability. MOSFETs are controlled by a gate triggering circuit to turn them on and off. The control signal wave form is shown in Figure 4. When the MOSFET is turned on for a time t_{on} , the voltage across inductor is PV voltage V_{PV} minus battery bank, V_B . During the period when the MOSFET is turned off for a time t_{off}, the voltage across inductor equals V_B[18].The average voltage across inductor must be zero under steady state. Given the fixed voltage at which the maximum power is obtained and the battery voltage, the duty cycle that will achieve that is calculated as follows:

$$V_B \cdot t_{off} = (V_{PV(max)} - V_B) \cdot t_{on} \qquad (1)$$

$$V_{PV(max)} \cdot t_{on} = V_B \cdot T \qquad (2)$$

Then equation(3) becomes

$$D = \frac{V_B}{V_{pv(\max)}} \qquad (3)$$

Where

T is the chopping period D is duty cycle of the DC-DC converter , $0 \le D \le 1$ since T is greater or equal to t_{on}

$V_{PV(max)}$ is the PV voltage at the maximum power point

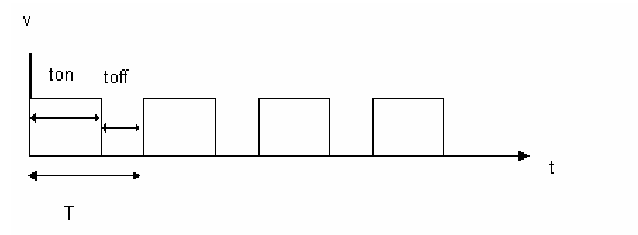

Figure4. Signal Control Waveform

This method of controlling the voltage by duty cycle is known as PWM (pulse width modulation) technique. Since the battery bank voltage is fixed, the PV voltage can be varied by changing the duty cycle, D, using equation (3). The MOSFET are switched on and off by a PWM signal. At the same frequency and irradiance, longer t_{on} causes lower PV array voltage and higher PV array current than shorter one.

Six power MOSFETs are connected in parallel to carry the high current during t_{on} and to reduce losses by reducing drain-source resistance [19]. Six diodes rated 30 A each, are used in the MPPT circuit with 600V DC blocking voltage and instantaneous forward voltage of 1.5V [20] .The inductance is used to reduce the ripple current of the load.

The external gate triggering circuit implemented to control the MOSFET is shown in Figure5. The components are listed in appendix A. The analog logic circuit uses PWM technique to vary the duty cycle and is connected to an isolated supply of +/- 15V. The operational amplifiers, U1 and U2 produce a high frequency triangular signal to compare at U3 with reference voltages that result in a rectangular signal. Furthermore, this duty cycle adjustable signal is passed through a phototransistor optocoupler to a gate drive circuit to drive the MOSFETs. This optocoupler is used to separate the generated PWM circuit from MOSFETs. The gate drive circuit used push-pull method to sink and source current from/to MOSFETs. The gate drive circuit consists of small MOSFETs, M1, M2 and small transistors and µA 555 as Schmitt trigger.

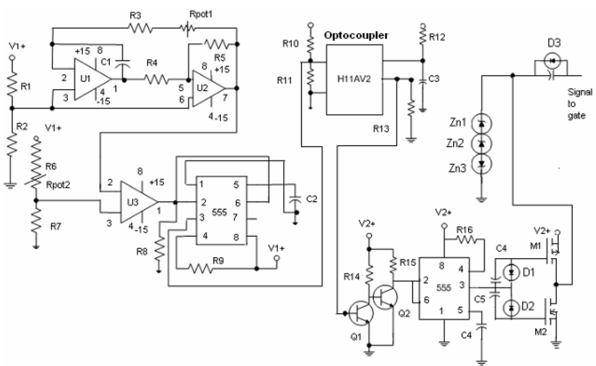

Figure5. Gate Triggering Circuit

IV. Experimental Results

The MPPT was connected to a 2.5kW PV array, a 24V battery bank and an inverter. The system was in operation and data was collected for two years. The MPPT's efficiency was about 90% at irradiance of 900 W/m^2, meanwhile the efficiency was reduced eminently at irradiance below 300 W/m^2.

In the experimental operation, duty cycle varied between 0.27 and 0.39 for different irradiances. For irradiances more than 700 W/m^2, the maximum power points were close to each others. The measurement data was computed to evaluate the MPPT's efficiency at different irradiances. The curves of the MPPT output power (P_{out}) and efficiency (%) at irradiances of 800 W/m^2 and 900 W/m^2, respectively, were plotted as shown in Fig. 6 and Fig. 7. The maximum efficiency for irradiance at 900 W/m^2 is 90.2%.

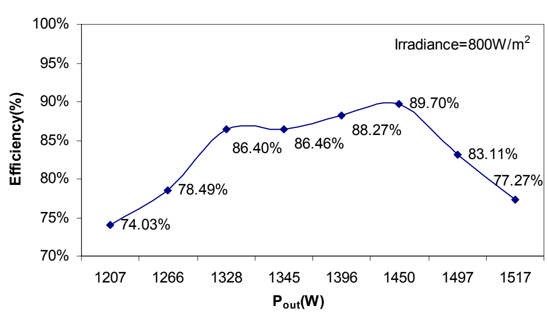

Figure6. Output Power versus Efficiency at irradiance= 800 W/m^2

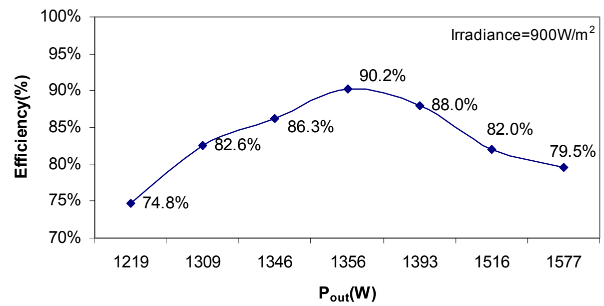

Figure7. Output Power versus Efficiency at Irradiance= 900 W/m^2

V. Conclusion

The designed step-down MPPT operates at about 90% efficiency at 900W/m^2 with a battery bank and an inverter. MOSFETs are controlled using PWM technique. MOSFETs and diodes and other components are inexpensive. The MPPT is simple and reliable. It has been working for two year without any problem .This MPPT extracts maximum power from a 2.5 kW PV array to a battery bank at high current output. In addition this MPPT work effectively greater than 82 % with sun irradiance more than 800 W/m^2.

Appendix A.

1.Component Value for gate triggering circuit

Component	Unit	Component	unit
R1,R9	10kΩ	R14	100kΩ
R2	5.6kΩ	R15	10kΩ
R3	2.2kΩ	R16	10kΩ
R4	4.7kΩ	Rpot1	10kΩ
R5	15kΩ	C1,C2,C5,C6	0.001µF
R6	5.8kΩ	C3	3.39µF
R7	2kΩ	C4	0.15µF
R8	27kΩ	Zn1	1N4733
R10	5.1kΩ	Zn2	1N5237
R11	2.2kΩ	Zn3	1N4739
R12	10kΩ	D1	1N4001
R13	1kΩ	Rpot2	500k

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