An Integrated Design of an Auto Clean and Cooling Smart PV Panel

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Abstract- This paper presents a design of solar tracking system driven by 12V or 24V DC motor controlled by a microchip 'Intelligent Drive unit IBL2403'[1]. The proposed double axis rotation solar tracker ensures the optimization of conversion of solar energy to electrical energy by orientation of 'titanium-oxide' PV panels' [2-6] in accordance to the hemispherical position of the Sun. The hemispheroidal three dimensional rotational axle moves the PV panel along the sun-path. Efficient cooling system and dust control mechanism has been designed for maximum efficiency.

Keywords- Smart PV panels (SPV), Titanium-oxide PV cells (ToPV), hemispheroidal axle, and solar-tracker, Cooling-cum-Cleaning system.

I. INTRODUCTION

The increasing demand for energy, the continuous reduction in existing sources of fossil fuels and the growing concern regarding environment pollution, have pushed mankind to explore new technologies for the production of electrical energy using clean, renewable sources, such as solar energy, wind energy, etc. Extracting useable electricity from the sun was made possible by the discovery of the photoelectric mechanism and subsequent development of the solar cell – a semi-conductive material that converts visible light into a direct current. By using solar arrays, a series of solar cells electrically connected, a DC voltage is generated which can be physically used on a load. Solar panels are being used increasingly as efficiencies reach higher levels, and are especially popular in remote areas where installation of electricity lines is not economically viable.
In our proposed design we have a DC motor'[7] intelligently controlled by a dedicated drive unit that moves a ToPV panels according to the signals received from the two simple yet efficient light sensors. Innovative technology has been developed for continuously cooling the surface of the ToPV panel, in addition to which highly-reflective mirrors have been used for greater solar incidence.

II. METHODOLOGY

The previous design of the system was:

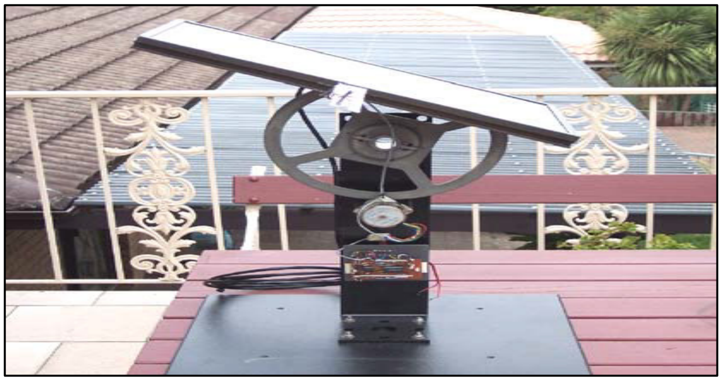

Figure-1: Single-axis rotating PV panel' [2]

In figure-1, it was observed that on an average silicon-based PV panels produced 8-10watts per square foot of solar panel area. Assuming this panel to be (6x6) sq. ft., producing 0.324KW/hr.
On average sunlight is available for 5hrs a day, therefore in a year it produces:
= (0.324*5*365) KW/hr
= 0.591MW/hr ………………. (1)
In this paper we have tried to improve the electric power produced by the PV panels.

III. Components of the SPV

A. Titanium-Oxide PV panel

The SPV will be made of titanium-diode cells which have a 32% conversion rate (solar energy to electrical energy) compared to the traditionally used silicon-based PV cells which have 13% conversion rate.

B. Renewable Light-weight High-Reflective mirrors

It is a new approach on reflector technology replacing heavy, energy intensive glass-based reflecting mirrors with light-weight low cost mirror technology. This device functions by reflecting light energy from a larger reflective surface area and focuses and concentrates this light energy into a smaller area.

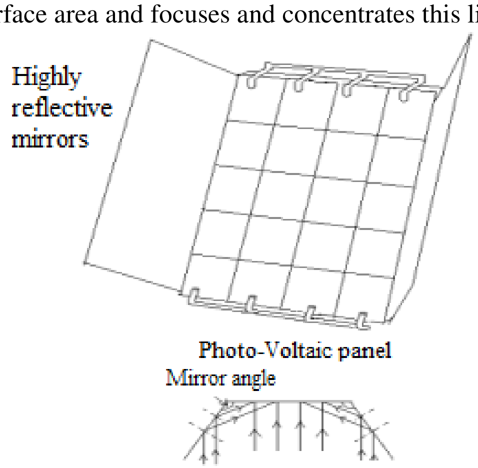

Figure-2: Reflecting mechanism

C. Panel Cooling-cum-Cleaning system

The designed ToPV will have a unique water-cooling system comprising of a water pipe-line on the rear sides which has a thermostat attached to it and is gravity-controlled. It only sprinkles water when the panel rises to a critical temperature. The sprinkler is gravity controlled and recycles water used by it, attaining 0% water wastage. It also safeguards the panel from dust accumulating on its surface.

D. Hemispheroidal Axle

Most importantly the ToPV system is mounted on a hemispheroidal axle, which is capable of horizontal as well as vertical rotation, allowing it to be used universally.

E. 12V,130W Electronically Speed Variator DC motor gear system

Two geared low power, low rpm, DC motor'[8] will be used for axle rotation, which will use a battery that will be charged by the power generated by SPV. A 12V, 130W (666mm*1486mm*35mm) weigh 8.3kg with additional mirrors installed, approximated weight of each unit would be 10kg.

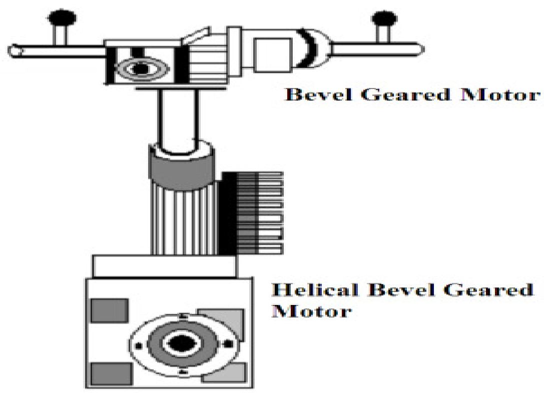

Figure-3: Electronic Speed Variator [16][17]

F. Intelligent drive unit IBL2403

The DC motor would be controlled by an intelligent drive unit IBL2403, for simultaneous rotation of three-dimensional axle for the SPV.

IV. PROPOSED DESIGN OF SPV AND ITS WORKING

A typical solar tracking PV system must be equipped with two essential features:
Azimuth tracking for adjusting the tilt angle of the surface of the SPV array during changing seasons.
Daily solar tracking for maximum solar radiation incidence to the PV array.

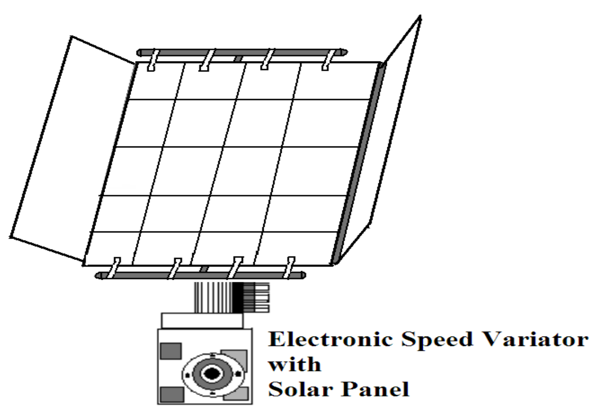

Figure-4: Proposed Design of SPV

The solar cell is composed of the semiconductors of the P-N junctions. It can convert light into electric energy. Therefore we assume the electricity produced due to sunlight can be used for common purpose.

The equivalent circuit of a solar cell:

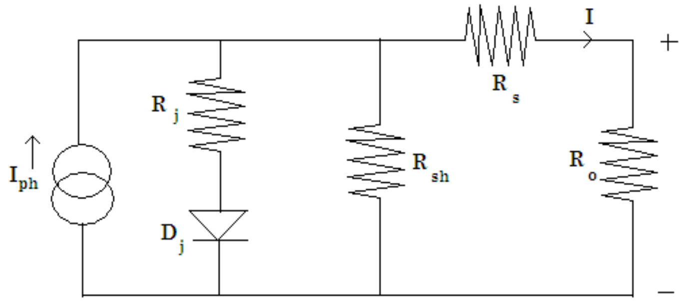

Figure-5: Equivalent Circuit

I_{ph} is the electric current generated from sun beaming on the ToPV, R_j is the non-linear impedance of the P-N junction, D_j is the P-N junction diode. R_{sh}, Rs is the equivalent line-up with the interior of the materials and connecting resistances in series. R_s is large and R_{sh} is small therefore neglected for analysis. R_o is the external load. I, V are the output current and output voltage respectively.
The relation between output current & output voltage is' [9]:

$$I = n_p I_{ph} - n_p I_{sat}\left[\exp\left(\frac{q}{kTA}\frac{V}{n_s}\right) - 1\right] \quad (2)$$

n_p is the parallel integrator of solar cell, and n_s, being the series connected integrator, q is the charge of a electron(1.6 x 10^-19), k Boltzmann Constant, A is Ideal factor of the solar cell(1-5). I_{sat} is the reverse saturation current.

This reverse saturation current can be determined by [9]:-

$$I_{sat} = I_{rr}\left[\frac{T}{T_r}\right]^3 \exp\left[\frac{q}{kA}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right] \quad (3)$$

T_r is Reference temperature for solar cell, I_{rr} is Reverse saturation current when solar cell reaches temperature Tr. Egap is the energy needed for crossing the energy band for semiconductor materials (the crystalline E_{gap} is approx. 1.1eV). From here we can study that higher the temperature greater is the reverse saturation current which decreases the output current. So, cooling of the system is very important.

V. COOLING & DUST-CONTROL MECHANISM

As observed cooling is an integral part to increase the efficiency of the solar output, innovative cost-effective technology has been devised for this purpose.
Cooling will be completely water controlled, as every household in India places the storage water on their rooftops so the higher potential energy of the water supplies the required water to the solar panels. Salt deposits on PV panels is avoided by attaching a piece of Potassium Aluminium Sulphate [$KAl(SO_4)_2,12(H_2O)$] on the interior side of the roof of water supply tank'[18].
Reason: When the water gets in contact of the potassium alum, the contaminants precipitate and clean fresh water is supplied. Potash Alum is cheaply and widely available in market.
As per tracking rules the solar panel is always parallel to the sun-rays, so when the sun reaches the horizon during sunset, the panel is placed perpendicular to the ground. So due to its position the incidence of atmospheric dust gets reduced.

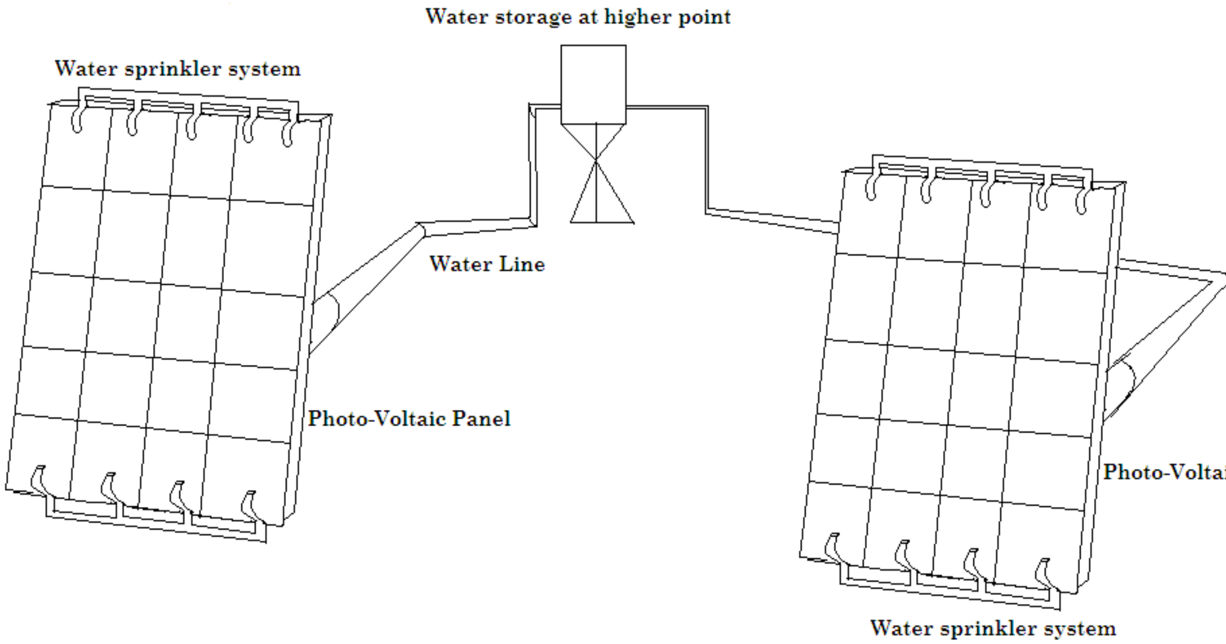

Figure-6: Water supply mechanism

The water from the storage is channelled through a regular PVC pipes which connects to the rear side of SPVs. The SPVs have sprinkler system on the top and bottom of the panel for efficient cooling. To prevent continuous flowing and wastage of water, the sprinkler will be attached with thermostats, that will allow flow only if the ToPV rises to a critical temperature. The sprinkler system is also gravity controlled so the water always flows down from top to bottom when required.

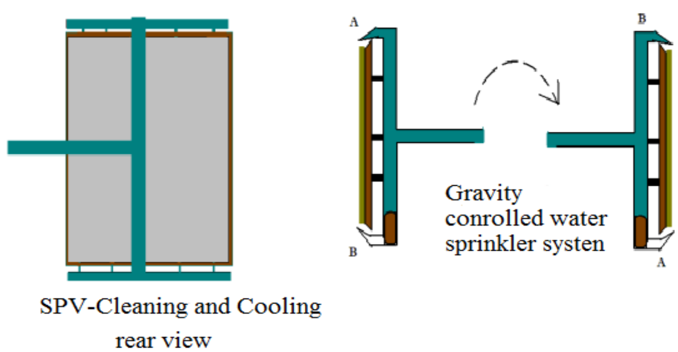

Figure-7: SPV Cleaning and cooling mechanism

VI. CONTROL MECHANISM: USE OF INTELLIGENT DRIVE UNIT

The Intelligent drive unit IBL2403 will control the rotation of axle and base DC motor on the basis of the input signals from the highly-sensitive light sensors. The light sensors will track the path of the Sun across the space, throughout the year.

The general summer and winter solstices and the sun path are illustrated in the figure[10-11]:

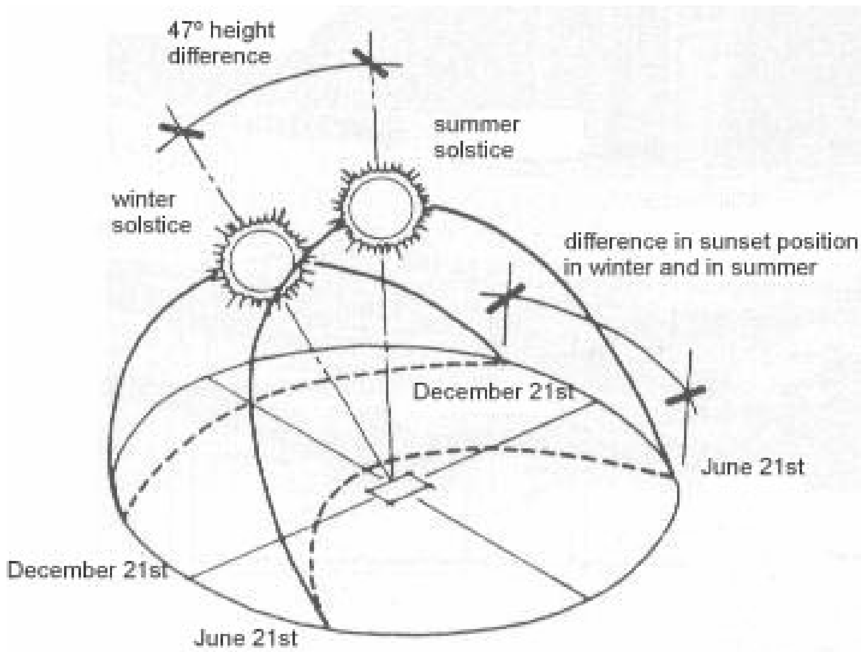

Figure-8: Summer and Winter Solstices

Intelligent drive unit IBL2403'[12] is a completely digital drive system, executed using DSP technology, dedicated to the command of DC electric motors, sinusoidal or trapezoidal commutated brushless motors or stepper motors. It accepts as position sensors, incremental encoders, digital or linear Hall sensors. IBL2403 allows the command of the motor in voltage mode, current loop, speed or position loop. Being a control system in distributed architecture, it will be placed close to the electric motor, removing the distance problem, connecting wires and perturbations appearing for centralized control solutions.

The IBL2403 drive unit can be used in multi-axes structures; thus the proposed solution can be extended to an array of PV panels that can communicate with each other and with central computation unit by a CAN-bus communication line.

The IBL2403 unit is a drive unit programmable in the high level language TML (Technosoft Motion Language), which allows:

- the setting of various movement modes: profiles, PT, PVT, electronic cam, extern, etc.,
- online modification of movement mode,
- the execution of "homing" type movements,
- the execution of decisions in the program, jumps or TML function calls;
- handling of digital and analogical I/O ports of the drive unit;
- the execution of arithmetic and logical operations;
- communication among axes and the control of the movement of other axes;
- synchronized with other axes from a multi-axis system.

To access the drive unit, to set the drive parameters and to implement the motion application, one can use the Easy Motion Studio program, an integrated graphical platform that simplifies the application development. The main characteristics of the IBL2403 'drive unit are the following:

- Completely digital drive, multi-motor (the same unit can control DC motors, sinusoidal or trapezoidal commutated brushless motors, and stepper motors);
- Voltage control, torque control, speed control of position control of the machine;
- Programmable motion modes: trapezoidal profile, S-curve, PT, PVT, electronic cam or gear box, external or analogue reference, 33 Home modes;
- 5 programmable digital inputs;
- 2 programmable digital outputs;
- Communication protocols RS-232 and CAN;
- 1.5 kB RAM memory;
- 8 kB x 16 EEPROM memory;

- Rated frequency of PWM: 20 kHz;
- Supply voltage: 12-28 V, rated current 3 A, peak current 6 A,
- Compact design.

The layout of the IBL2403 drive unit and the connection of this drive to the DC motor and to the supply source are presented in Figure-9.

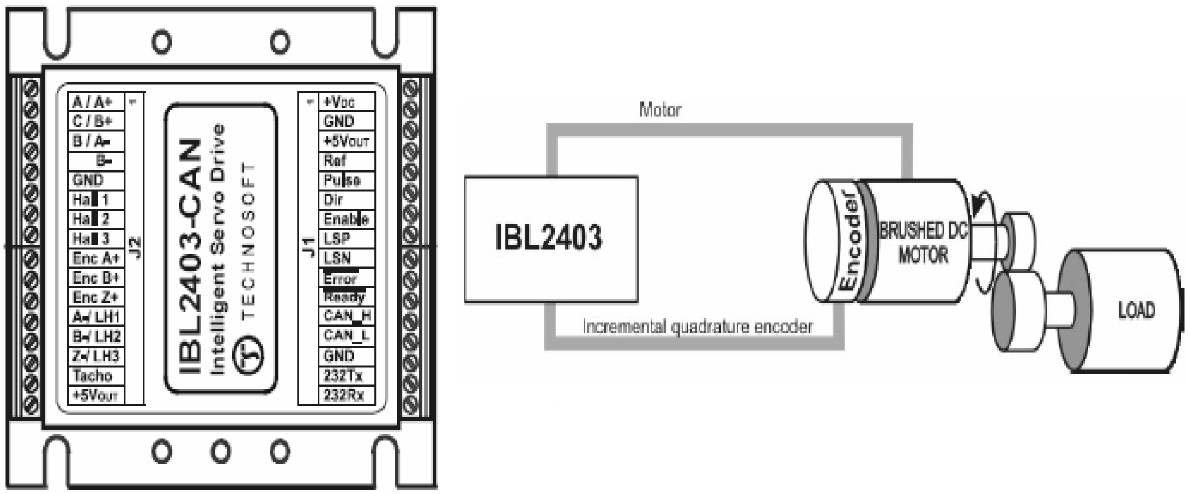

Figure-9: IBL2403 with motor & load.

VII. RESULTS AND SIMULATION:

A simulated graph of a fixed solar panel and a tracking panel is illustrated' [13]:

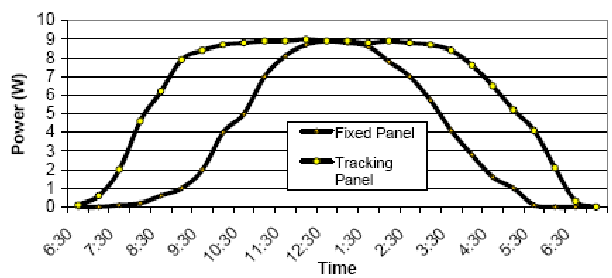

Figure-10: Simulated results of power increase for tracked SPVs**.**

Generally silicon-based PV cells have 13% conversion rate of solar to electrical energy'[14], but the Titanium-oxide PV (ToPV) panels have a 32% conversion rate.
For a fixed solar panel the efficiency of receiving solar energy is only 39% while for a tracking panel is 70%.
The proposed SPV has two highly reflective mirrors placed at an angle on the sides, increasing solar incidence by 20% at minimum.
The problem of over-heating and dust accumulation has been smartly dealt with the auto-cleaning which further increases the efficiency of the SPVs'.
The use of Intelligent drive unit IBL2403 also facilitates the use of artificial intelligence. The unique water-cooling system and dust control mechanism using thermostat and gravity control mechanism makes solar energy conversion smart.
The proposed design of SPV mounted on a hemispheroidal axle allows it to be used in any part of the world, making it for universal location application.[15]

The following chart is a simulated representation of how tracked SPVs' are more useful than fixed panel systems and with more improvements proposed in this paper, the output power of solar power generation is bound to increase.

Output Current(mA)		
Time (hrs)	**Fixed PV**	**Tracking PV**
8:00	0.42	0.85
9:00	0.55	0.91
10:00	0.75	0.92
11:00	0.81	0.95
12:00	0.92	0.99
13:00	0.95	0.99
14:00	0.88	0.99
15:00	0.76	0.98
16:00	0.42	0.95
17:00	0.23	0.95
18:00	0.08	0.72
Total	**6.77**	**10.2**

Figure-11: Simulated Chart Fixed panel vs. SPV

VIII. CONCLUSION

Generally silicon-based PV cells have 13% conversion rate of solar to electrical energy'[14], but the Titanium-oxide PV (ToPV) panels have a 32% conversion rate.

For a fixed solar panel the efficiency of receiving solar energy is only 39% while for a tracking panel is 70%.

The proposed SPV has two highly reflective mirrors placed at an angle on the sides, increasing solar incidence by 20% at minimum.

The problem of over-heating and dust accumulation has been smartly dealt with the auto-cleaning and cooling which further increases the efficiency of the SPVs'. The use of intelligent drive unit IBL2403 also facilitates the use of artificial intelligence. The unique water-cooling system and dust control mechanism using thermostat and gravity control mechanism makes solar energy conversion smart.

Our proposed design of SPV mounted on a hemispheroidal axle allows it to be used in any part of the world, making it for universal location application.

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