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Photovoltaic power system based on MPP tracking technique to feed radar stations

By

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Abstract:

The photovoltaic power system, PVPS, converts the solar radiation directly to electricity without fuel , moving parts , noise and greenhouse gases emission then it's a clean and environmentally friend power system .

This paper introduces a complete design of PVPS based on energy balance condition , EB , and maximum power points , MPPs , tracking technique to feed the simulated load in an Egyptian remote site ,Marsa-Alam. This load consists of four radar stations , automatic command center , manual command center , communication center , charging center and lighting for the radar battalion . Also, the design parameters obtained by applying the EB have been compared with the design parameters obtained by using the MPPs tracking technique. A new computer Matlab Program has been designed and operated to determine the hourly MPP through the daily day time along the year.

Keywords:
Photovoltaic, power system, maximum power points tracking technique, energy balance condition, utility grid and solar cells module

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1. *Introduction:*

The electric energy is the one of the important indices of the development at any site. In the last years the demand on the electric energy is increased. In the same time the traditional sources for generating the electric energy (Fossil fuel) are decreasing continuously with the time and the reserve of the fossil fuel is decreased, also the price of fossil fuel is increased quickly.
The results are decreasing the generating energy now and followed by increasing the kWh price and the generation of the electric energy using the fossil fuel may be off at the long run. The prevision of the electric energy for any remote area from utility grid, U.G, is more expensive because the costs of over head transmission lines or cables and the distribution stations between the U.G and the equipments in the remote area are high. The diesel generator units are the sole source for generating electric energy in the remote areas, but they have many disadvantages as the high cost of fuel consumption, greenhouse gases emission, and noise according to the moving parts, cost of repairing and spare parts (technical supporting) and low part load efficiency. The renewable energy sources for generating electrical energy (solar, wind, water, fuel cells…) are the most alternative sources instead of the fossil fuel sources especially for feeding the loads in the remote area. They are clean and environmentally friends electric energy sources. The photovoltaic power system, PVPS, converts the solar radiation directly to electricity without fuel, moving parts, noise and greenhouse gases emission and is a clean and environmentally friend power system.

2. *Problem Statement:*

Marsa–Alam is important, promising tourism and nice weather site (has long sun chine time), [1], The existing of the radar battalion here save the detection of any air target enter to it, gives alarm to higher command centers to take the suitable decision toward this target (friend or enemy and destroying by air forces or air defense forces if it is enemy) and by this the protection for Marsa –Alam and its international airport will be saved and this pulls more visitors and increases the input of the tourism and also increases the Egyptian national input. Marsa- Alam has a latitude φ=25° 5´ o˝ N and Longitude of 34° 5´4 o˝ E. The radar battalion situated in this site consists of four radar stations. These radar stations detecting any air target in the daytime or night period and giving the coordinates (h, ε, β, r) of the target to the command centers.

The load of the four radar station under study can be described as follows:

1) R1 has 3 diesel generators each of them is 60 kW, 3Ø, 220V and 50 HZ. One of them is the main generator and the others are reserve. The actual consumed power is 28 kW.

2) R2 has 3 Diesel generators each of them is 30 kW, 3Ø, 220V and 50 HZ. One generator is the main and the others are reserve. The actual consumed power is 12 kW
3) R3 has 3 Diesel generators each of them is 30 kW, 3Ø, 220V and 50 HZ. One generator is the main and the others are reserve. The actual consumed power is 12 kW
4) R4 has 2 Diesel generators each of them is 25 kW, 3Ø, 220V and 50 HZ. One generator is the main and the others are reserve. The actual consumed power is 12 kW

Also there is another load represented by:

1) Automatic command center has 2 diesel generators each of them is 100 kW, 3Ø, 220V and 50 HZ. One generator is the main and the others are reserve.
2) Manual command center needs 10 kW.
3) Communication center needs 5 kW.
4) Charging center needs 5 kW.
5) Lighting needs 50 kW.

The Radar Battalion operates in Maximum case and the power required is 100 %. Figure (1) shows the daily load curve of the load demand.

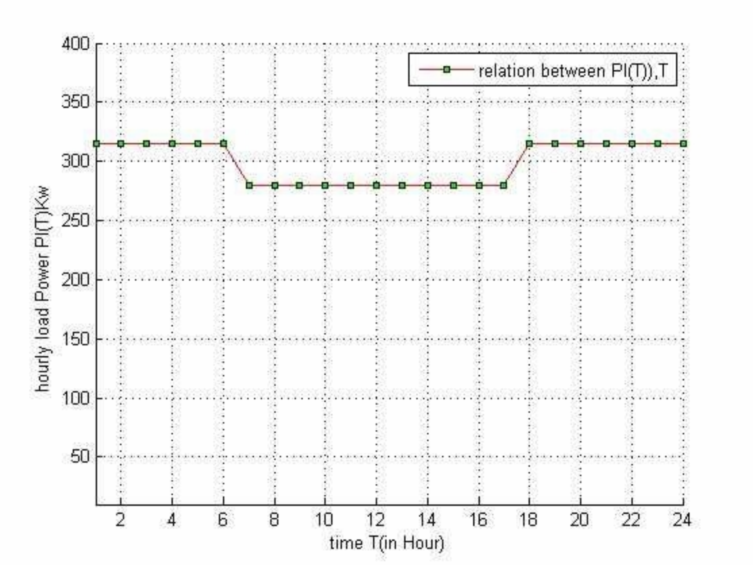

Figure (1): *the daily load curve of the Load demand*

The diesel generators which used to feed the above load have some problems in its fuel and maintenance and so on. For this reason it is recommended here to use the photovoltaic solar cells to feed the above load instead of the diesel engines where the Marsa- Alam site has a lot of solar radiation through the year seasons.

3. Design the Photovoltaic System Based on MPP

3.1Determination of PVPS design construction using Energy Balance Method.

3.1.1 Data required.

A. The solar hourly radiation incidents on the horizontal of Marsa – Alam site has been taken from the Metrological Authority of Egypt, [2]. Then this hourly radiation has been calculated to be on surfaces tilted by the monthly best tilt angle using the equation in reference [3] of:

$$S = \varphi - \delta \quad (1)$$

Table (1) shows the monthly best tilt angle. Then the radiation on the tilted surfaces has been calculated by using the equations in ref [4]. Figure (2) displays the hourly radiation of Marsa –Alam on the tilted surfaces for the four year seasons.

Table (1) *the monthly best tilt angle of Marsa-Alam of φ=25° 5´ o˝ N*

Month	δ°	S°
January	-20.92	45.92
February	-12.95	37.95
March	-2.42	27.42
April	9.41	15.59
May	18.79	6.21
June	23.09	1.91
July	21.18	3.82
August	13.46	11.55
September	2.22	22.78
October	-9.6	34.6
November	-18.91	43.91
December	-23.05	48.05

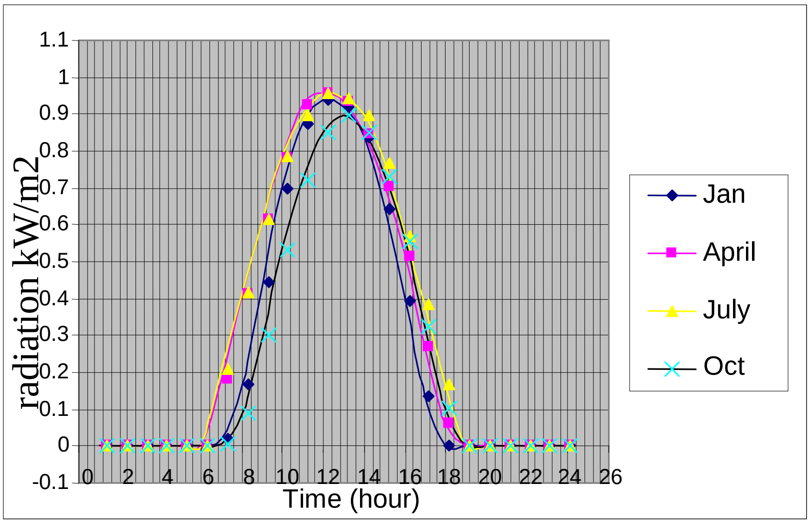

Figure (2): *the hourly radiation (kW/m²) of Marsa –Alam on the tilted surfaces for the four year seasons summer (July), autumn (Oct), winter (Jan), spring (Apr).*

B. The ambient temperatures of Marsa – Alam site are shown in Table (2), [2].

Table (2): *The ambient temperature of the selected site*

Month	Max. °C	Min. °C
17 January	21.1	14.4
16 February	20.6	14.3
16 March	20.1	13.4
15 April	25.2	16.8
15 May	32.6	22.1
11 June	38.2	30.9
17 July	33.4	27.1
16 August	34.6	27.7
15 September	32.9	27.2
15 October	29.4	22.5
14 November	25.4	18.6
10 December	22.6	16.4

C. The solar cells Module type of FVG – 185M-MC, [5], has been selected for this study. The characteristics of this solar cell Module type are displayed in Table (3).

Table (3): *the characteristics of the selected solar cell Module type.*

Module Type / **Item**	FVG 185M-MC [5]
Module efficiency	14.60%
Cell efficiency	17.50%
Maximum power (P_m)	185(w)
Voltage at pm (V_{mp})	37.50 Vdc
Current at pm (I_{mp})	4.90 A
Short-circuit current (I_{sc})	5.40 A
Open-circuit voltage (V_{oc})	44.5 Vdc
Temperature coefficient of I_{sc}	(2.7±0.5) mA/°C
Temperature coefficient of V_{oc}	- (150±10) mV/°C
Temperature coefficient of Pm	- (0.43%)/°C
Nominal operating cell temp (Noct)	47±2°C
Maximum-system voltage (VDC)	700 Vdc
Dimensions, m	1.581×0.809
Area, m^2	1.279029 m^2
Cell Temp (Tc)	25°C
Cells and number	Mono-crystal line silicon -72 cell
Maximum series fuse rating	7A

D. Table (4) reveals characteristics of the selected DC-AC Inverter.

***Table (4):** The characteristics of the selected inverter unit*

Item \ Type	Grid Tie Inverter GT- 100E,[6].
Continuous power rating	100 KW AC
Nominal DC power rating	105 KW DC
Nominal AC voltage	400 VAC three phase
Nominal AC frequency	50 Hz
Line power factor	> 0.99 above 20% rated power
Maximum Ac line current	164 amp Ac
AC current distortion	< 3% THD at rated power
Max open circuit voltage	650 VDC
Power tracking windows range	300 to 600 VDC
Max DC input current	319 amp DC
Peak inverter efficiency	95.5%
Average input DC voltage	(300+600) /2 = 450 VDC
Average input DC current	(100*1000) / 450 = 222.22 A
Ambient temperature range	- 10°C to + 45 °C

3.1.2 Estimation the PVPS Construction, [3].

The Size of solar cells required to feed the load under study has been determined by using the Energy Balance method, [3]. Table (5) display the construction of the designed PVPS using the selected types of PV module and Inverter unite.

***Table (5):** The construction of the designed PVPS using the selected types of PV module and inverter unit.*

Item	Requirements
Type of PV module.	FVG 185 M- MC, [5].
Type of inverter unit.	Grid Tie inverter GT-100 E,[6].
Module active area, m^2.	1.279029 m^2
Optimum Solar Cells Area, OSCA, m^2.	9750.00 m^2
Number of series modules/string, Ns.	12 module
Number of parallel string/subsystem, Np.	45 string
Number of modules / subsystem, Nt = Ns* Np.	540 Module
Number of subsystems	14 subsystems
Number of inverter units, INU.	14 INU
Solar cell area of one subsystem, SOSCA	690.67566 m^2
Optimum number of modules, ONpv	7623 Module or 14×540=7560

Without MPPT:

- The Total Yearly Energy of the Load, (TYEPL) is as following:
  TYEPL = 7175 kWh * 365 = 2618875.00 kWh.
- The Total Yearly Energy of the PV output, (TYEPV) is as following:
  TYEPV = 86183.539(kWh) * 30.4 = 2619979.586 (kWh).
- OSCA= 9750 (m^2).
- SOSCA= 690.675 (m^2) = 691(m^2).
- Number of subsystems = number of INU = 14.
- Number of modules /subsystem = 12*45= 540 modules.
- Total number of modules in PVPS =14 *540 = 7560 modules.

Figure (3) shows the configuration of one subsystem.

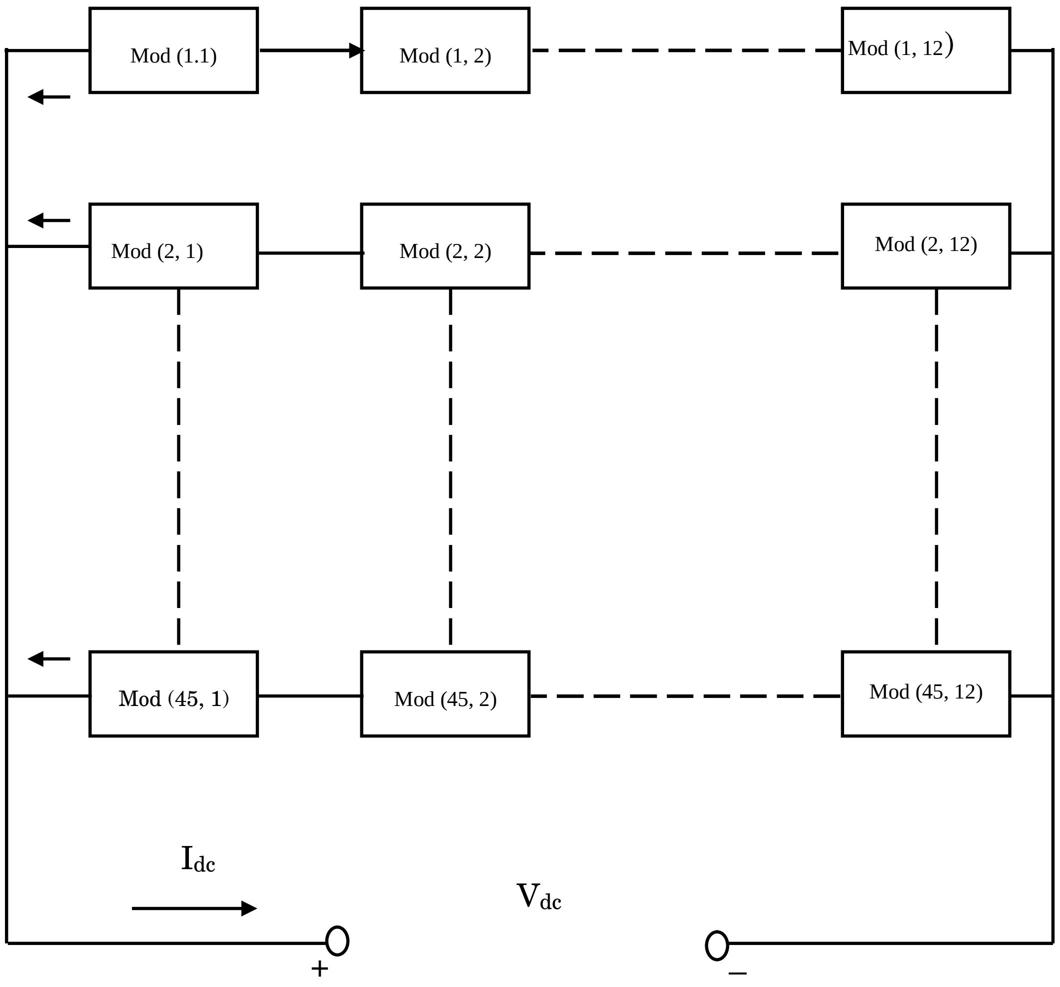

Figure (3): the configuration of one subsystem.

The one subsystem has the following data:

- Imp = 45 x 4.9 (ADC) = 222.222 (ADC) = I_{dc}
- Vmp = 12 x 37.5 (VDC) = 450 (VDC) = V_{dc}
- Isc = 45 × 5.40 (ADC) = 243 (ADC)
- Voc = 12 × 44.5 (VDC) = 534 (VDC)
- Pmp = 450 × 222.222 = 100 kW DC = P_{dc}

3-2. Determination of PVPS Construction Based on MPP.

The equivalent electrical circuit describing the solar cells module or array used in the analysis is shown in Fig (4), [7]. The circuit consists of a light-dependent current source, I_L or I_{ph}, an internal shunt resistance, R_{sh}, with very high value and series resistance, R_s, with value as low as possible, so that most of the available current, I, can be delivered to the load.

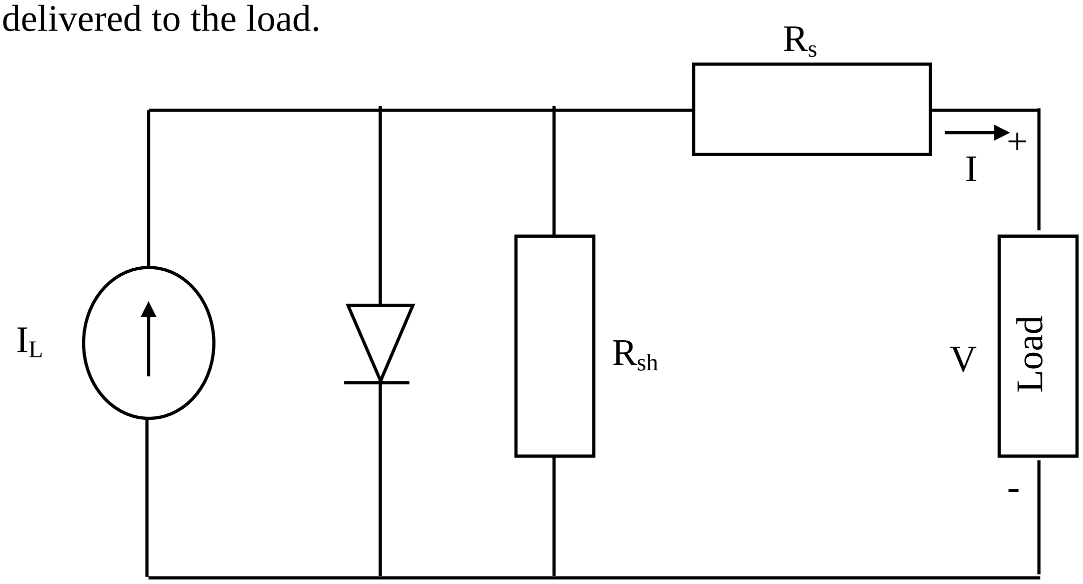

Figure (4): Equivalent circuit for a solar cells module or array

The module or array equivalent circuit output current, I, as a function of output voltage, V, as follows [8]:

$$I(v)=I_{sc}\left\{1-C_1\left[\exp\left(\frac{V+\Delta V}{C2V_{oc}}\right)-1\right]\right\}+\Delta I \quad (2)$$

$$C_2=\frac{(Vmp/Voc)-1}{In\left(1-\left(I_{mp}/I_{sc}\right)\right)} \quad (3)$$

$$C_1=\left(1-\left(I_{mp}/I_{sc}\right)\right)*\exp\left[-V_{mp}/\left(C_2*V_{oc}\right)\right] \quad (4)$$

$$T=TA+q*H_T \quad (5)$$

$$\Delta T = T-T_{ref} \quad (6)$$

$$\Delta I=\alpha\left(H_T/H_{ref}\right)*\Delta T+\left(\left(H_T/H_{ref}\right)-1\right)*I_{sc} \quad (7)$$

$$\Delta V=-\beta_1*\Delta T-R_s*\Delta I \quad (8)$$

$$R_s=\frac{V_{oc}-V_{mp}}{I_{mp}}. \quad (9)$$

$$\mathbf{R_{l} = V_{mp} / I_{mp}} \quad (10)$$

A MTLAB computer program has been designed to determine the hourly maximum power point and its power for the PVPS.

Figure (5) shows the flowchart of this program. The input data required to the program are:

(a) The characteristics of the selected solar cells module (one subsystem) which can be rewritten from subsubitem (3-1-2) as follows:

$\mathbf{V}_{mp}$ = 450 V, $\mathbf{V}oc$ = 534 V, $\mathbf{I}_{mp}$ = 222.222 A, $\mathbf{I}_{sc}$ = 243 A,

R_s =0.38 Ω at Standard Test Condition (STC)

(b) From Table (3) it is found that:

α=0.003 A/˚C, β_1=-0.15 V/˚C

q = 0.03

R_L= 2.03 Ω

(c) The ambient temperatures of the selected site T_A which are displayed in Table (2).

(d) The hourly solar radiation which incidents on the tilted surface, Fig (2).

The program outputs are $\mathbf{I}_{mp}$, $\mathbf{V}_{mp}$ and $\mathbf{P}_{mp}$ in each hour from 7 to 18 for each month from January to December.

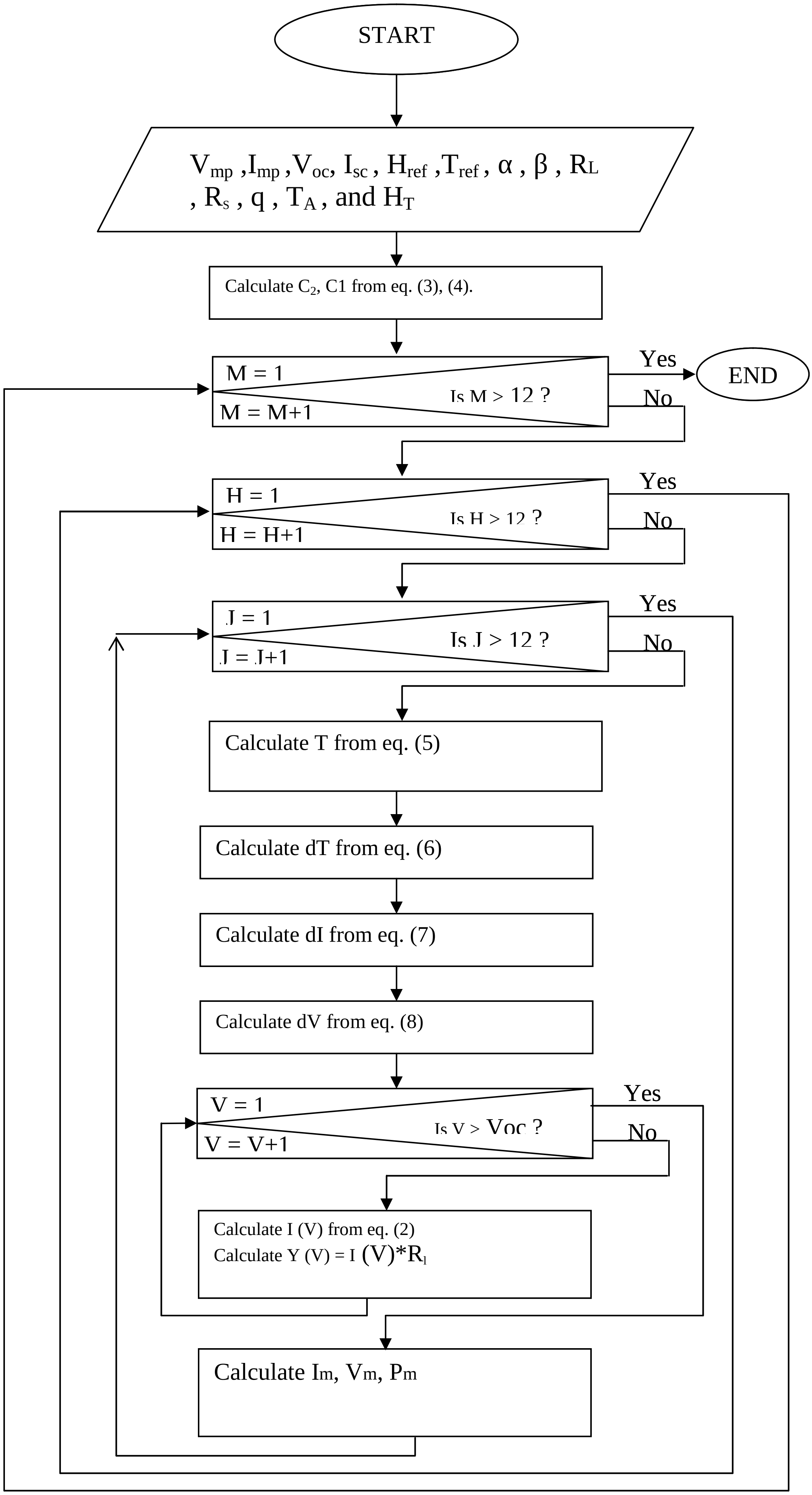
START
Vmp ,Imp ,Voc, Isc , Href ,Tref , α , β , RL , Rs , q , TA , and HT
Calculate C2, C1 from eq. (3), (4).
M = 1
Is M > 12 ?
M = M+1
Yes
END
No
H = 1
Is H > 12 ?
H = H+1
Yes
No
J = 1
Is J > 12 ?
J = J+1
Yes
No
Calculate T from eq. (5)
Calculate dT from eq. (6)
Calculate dI from eq. (7)
Calculate dV from eq. (8)
V = 1
Is V > Voc ?
V = V+1
Yes
No
Calculate I (V) from eq. (2)
Calculate Y (V) = I (V)*Rl
Calculate Im, Vm, Pm

Figure (5): *The flowchart of the program designed to determine the maximum power point and its power for the PVPS.*

Table (6) shows the total monthly PVPS output power, load power, surplus power and deficit power (kWh) for Jan to December with and without MPPT.

Table (6): Total Monthly PVPS output power, Load power, surplus power and deficit power (kWh), with and without MPPT

Month	**With MPPT**				**without MPPT**		
	Pvo(t) (kWh)	**surplus (kWh)**	**Deficit (kW)**	**Pl(t) (kWh)**	**Pvo(t) (kWh)**	**surplus (kWh)**	**Deficit (kW)**
Jan	7503.785	5209.508	4880.723	7175	6545.617	3958.017	4587.40
Feb	9562.257	7127.73	4740.473	7175	7629.042	4792.442	4338.40
Mar	10276.274	7695.605	4594.331	7175	7895.456	4936.566	4216.110
Apr	9042.636	6339.476	4471.833	7175	7588.132	4534.008	4120.876
May	8956.074	6156.751	4375.677	7175	7345.176	4186.929	4016.753
Jun	9123.269	6296.723	4348.454	7175	7166.908	4016.874	4024.966
July	9561.437	6673.712	4287.275	7175	7598.318	4423.551	4000.228
Aug	8548.752	5815.051	4441.299	7175	7141.935	4064.575	4097.64
Sep	8202.564	5624.455	4596.892	7175	6758.042	3859.643	4276.601
Oct	6892.345	4568.77	4851.425	7175	6118.538	3395.329	4451.791
Nov	9765.161	7371.942	4781.782	7175	7375.593	4692.839	4492.241
Dec	8776.271	6485.954	4884.683	7175	7020.782	4375.732	4529.950
$\sum$	106210.825	75365.677	55254.847	86100	86183.539	51236.505	51152.956

From the table (6) and the previous parameters it can be seen that:

With MPPT:

- TYEPV = 106210.825 × 30.4 = 3228809.08 (kWh)
  Then
- $\frac{\text{TYEPV (with MPPT)}}{\text{TYEPV (without MPPT)}} = \frac{3228809.08}{2619979.586} = 1.23$
- $\therefore \text{OSCA} = \frac{9750}{1.23} = 7926.83 \cong 7927\,(\text{m}^2)$
- Number of subsystems = $\frac{7927}{691} = 11.47 \cong 11\ \text{subsys}$
- Number of subsystem = Number of DC/DC converters = Number of DC/AC inverters = Number of 100 kW Ac 3Ø 400/220 V 50 Hz transformers = 11.
- Total Number Modules in PVPS = 11 × 540 = 5940 Modules

From the previous the system with MPPs Tracking technique is desirable where the MPPT technique saves:

- The area = 9750 – 7927 = 1823 (m^2)
- DC/DC converters = 3 units
- DC/AC inverters = 3 units
- 100 kW Ac 3Ø 400/220V- 50 Hz trans = 3 unit
- Modules = 3 × 540 = 1620 modules
- Finally the total costs can be reduced by $\left(1-\frac{11}{14}\right)\times\frac{100}{100}$ = 21.43 %

But if we stay using the PVPS with MPPT and with the same OSCA (9750 m2) to generate TYEPV = 3228809.08 kWh.

Then the excess energy is equal to:

3228809.08 – 2619979.586 = 608829.494 kWh/year.

This excess energy can be used for generating more hydrogen gas from sea water Via electrolysis processing and used as a fuel for the fuel-cells power systems (FCPS) with the air to generate electric energy feeded to the load during the night time or in the case of deficit in the output of the PVPS, Figure (6) Shows the power from PVPS at each hour from 7 to 18 (1-12) for Jan with and without MPP.

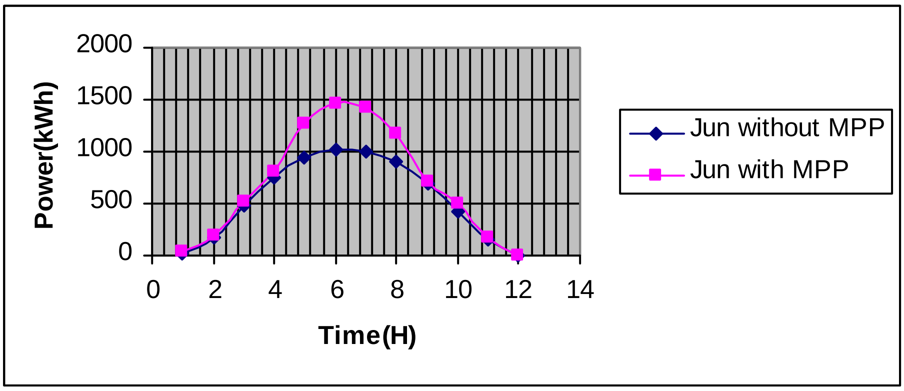

Figure (6): *the power from PVPS at each hour from 7 to 18 (1-12) for Jan with and without MPP.*

4. Conclusions:

This paper presents a new proposed method based on MPP tracking system. This method was computerized by A MATLAB computer program. This method with its computer program can be used to estimate the design parameters for a stand - alone photovoltaic power system to be installed at any site in the world. This method was applied to determine the design parameters of a stand - alone photovoltaic power system to be installed at Marsa- alam site as an Egyptian remote site to feed a load of a radar station and its accessories. By comparing the design parameters which found with the design parameters which obtained by applying the energy balance method for the same system it is found that:

1. The solar cells area decreased with 18.7% with respect to the results of applying energy balance method

2. The cost decreased with 21.43% with respect to the results of applying energy balance method

References:

[1] http://www.holiday-weather.com /marsa_Alm/averages/.
[2] Meteorological Authority of Arab Republic of Egypt, 2007.
[3] H. H. EL-Tamaly and F. M. EL-Kady, optimizing the integration of Photovoltaic/wind system with Electric utility, proceeding on Al-Azhar Engineering six international conference, p.69-80, September 2000.
[4] S. A. Klein, calculation of the Monthly Average insulation on the tilted surface, solar energy, vol. 19, p. 325-329, 1977.
[5] http://www.fvgenergy.com /photovoltaic-eng/ photovoltaic-module-160-185w-eng.html.
[6] http://www.renewpowers.com/GT-100E.html.
[7] Kyoung.Ro, Two-Loop controller for maximizing performance of a Grid – connected photovoltaic- fuel cell Hybrid power Plant, thesis, Blacksburg, Virginia April 1997.
[8] Bogdan S. orowy and Z. M. salameh, Methodology for optimally sizing the combination of Battery bank and PV array in a Wind/PV hybrid system, IEEE Transactions on energy conversion, Vol .11, No. 2, p. 367-375, June 1996.

Nomenclatures:

h: High or Altitude of the air target (km).
r: Slop range of the air target (km).
ε: Elevation angle of the air target (o —90° in vertical plane).
β: Azimuth angle of the air target (o—360° in horizontal plane) .
S: The monthly best tilt angle of solar cell modules or PV array, degrees,
φ: The site latitude for the location, degrees.
δ: Sun's declination angle, degrees, ranges between +/- 23.45˚.
I : Module or array output current, (Amps),
V: Module or array output voltage, (volts),
I_{mp}: Module or array maximum power current, (Amps),
V_{mp}: Module or array maximum power voltage, (volts),
V_{oc}: Module or array open circuit voltage, (volts),
I_{sc}: Module or array short circuit current, (Amps).
HT: Tilted radiation, (kWh).
H_{ref}: Reference radiation, (kWh)
R_s: Module or array series resistance, (ohms),
T: Cell temperature, (°C),
T_A: Ambient temperature, (°C),
T_{ref}: Reference temperature, (°C),

ΔT: Change in cell temperature, (°C),
q: Cell thermal resistance, (m^2. °C/kW),
α: Current change temperature coefficient at reference radiation, (Amp/ °C).
β_1: Voltage change temperature coefficient at reference radiation, (volts/ °C).
R_l: Load resistance, ohm.