DESIGN AND SELECTION OF A SOLAR POWER DRIVEN WATER PUMPING SYSTEM FOR PROPOSED WATER POCKETS IN POLGAHAWELA, POTHUHERA, ALAWWA INTEGRATED WATER SUPPLY PROJECT

D.M.S.A Dissanayake **IEng(UK), MSc.(SL), MIET(UK)**
Polgahawela, Pothuhera, Alawwa, Integrated Water Supply Project
National Water Supply & Drainage Board
Sri Lanka
e-mail: sampatharavinda70@yahoo.com

Abstract— **The main objective of this design is to introduce a sustainable power solution for remotely located pump houses of the National Water Supply & Drainage Board. The same pump houses are in the locations where continuous power interruptions happen in the CEB (Ceylon Electricity Board) power supply. Further, some of the newly planned pump houses are in the locations where the difficulties are available in getting the CEB power supply. Hence, this design is carried out to provide uninterrupted power supply to the mentioned pump houses and at the same time, to provide a sustainable solution by reducing incurring CEB electricity costs or Fuel costs for Diesel Generators. This in turn gives the benefit of Return-On-Investment (ROI) the NWSDB while giving an uninterrupted service to the consumers. One of the 8 numbers of Water Pocket solution pump houses will be selected to carry out the design and the selection of the relevant equipment will be commenced based on the results of the design calculations.**

1. INTRODUCTION

Polgahawela, Pothuhera, Alawwa Integrated Water Supply Project (PPAIWSP) of National Water Supply & Drainage Board is the largest water supply project conducted in North Western Province. The principle scope of this project is to facilitate 29000 m3/Day of water to 450,000 of consumers.

A distribution network is also being implemented under this project to lead the treated water to the consumers' end. This distribution network covers the Polgahawela, Pothuhera, Alawwa and Boyagane areas. However, there are some locations within the above specified region which the distribution pipelines cannot be laid. The identified reasons for the same are,

1. Insufficient of water line pressure at the beginning of the location.
2. High elevations of the location.
3. Embedded rocks in the soil and hence, it is too difficult to lay the distribution lines.

PPAIWSP hence proposed Water pocket solutions to serve the treated water for the people who live in above said locations too. A Water pocket is an end of a distribution line which has been coupled to a newly built water tank which is planning to be implemented at the start of the location. Further, the pocket solution tank is coupled with a pump house which boosts the consumed treated water to an adequate pressure to serve the consumers.

As per the contract agreement of the above water supply project, eight (8) numbers of Pocket Solutions to be implemented by the main contractor to accommodate the above task. Following locations have been identified to implement the Water Pocket Solutions.

1. Kandegedara High Elevated Area
2. Denagmuwa High Elevated Area
3. Polgahawela High Elevated Area
4. Yogamuwakanda
5. Boyagane High Elevated Area
6. Pothuhera High Elevated Area
7. Narammala
8. Alawwa-Ganekanda

Following figures 1 and 2 shows arrangement of a Water Pocket Solutions which is operated with and without an overhead stock tank, respectively.

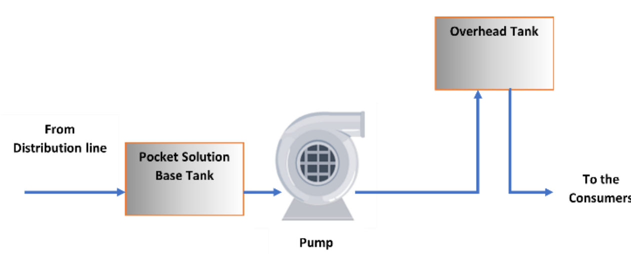

Fig. 1. Arrangement of Water Pocket Solution with Overhead Tank

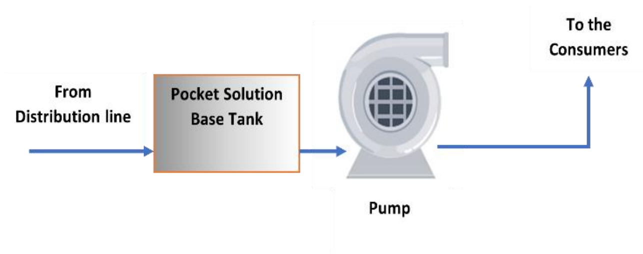

Fig. 2. Arrangement of Water Pocket Solution without Overhead Tank

A. *Difficulties in supplying power to the pocket solutions.*

Difficulties were found when arranging CEB electricity connections to the proposed locations of the water pockets as they are available in the remote areas. Implementing diesel generators to the same locations will not be a cost-effective solution as it affects on the Return-On-Investment (ROI) to the NWSDB compares with its fuel consumption cost. This situation will be same for CEB electricity connections since the pumps in the water pockets to be switched frequently as per the water supply demand of 80-150 consumer families served under a pocket solution. Hence, a solution for a power supply to be given for water pocket pump houses which is effective and lowering the operational costs for NWSDB.

B. *Proposing Solar Power Solutions to drive the Pumps in a Water Pocket Solution*

Considering above cost issues and the time constraints, proposing a Solar Electricity system to drive the pumps in Water Pocket Solution has found to be the most effective solution to address the above issues on power supplies. Here we select one location to design the system it is and Boyagane High Elevated Area.

As per the existing Demand, Head (in meters) and the Capacity (in Cubic Meters per Hour) 2kW is the rating of the motor of the selected water pump. Hence, the Solar System shall be designed to cater the above-mentioned solar rating. However, we need to consider following requirements before designing the system and design shall be carried out based on the same. [1]

1. Prevalence of the Sunlight will be 9 hours in average.
2. Hence, CEB supply should be kept as the Redundant Power Supply of the system as it is essentially required to operate the pumps of the pocket solution in the nighttime.

2. Designing of the Solar Power Driven Water Supply System

C. *Main Components of the Design*

Two main components will be used in this system and design calculations should be carried out in order to select the same components. Those are [3],

1. Solar Photovoltaic Panel
2. Solar power Pump Driver

Following fig. 3 shows about the arrangement of a Solar Pump Driven Water Supply System.

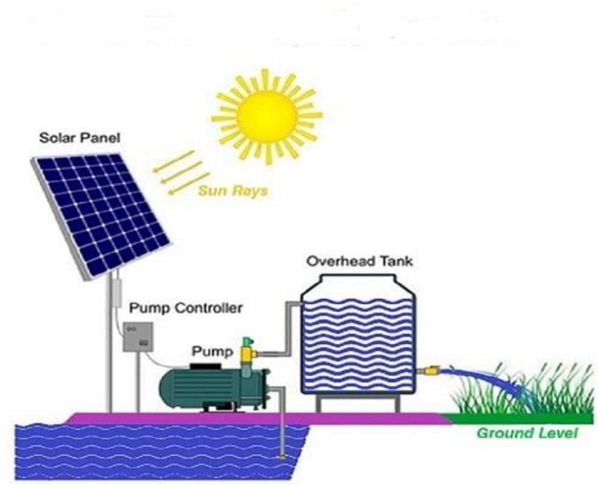

Fig. 3. Solar Power Driven Water Supply System

Here, the Solar Panel converts the Sun Light to the DC (Direct Current) electricity by using its Silicon Cells. These Solar Cells are not made with pure Silicon Cells as they are poor conductors. Therefore, pure Silicon is used for the construction of Semiconductors. In order to address this electricity conductivity issue, Silicon atoms are mixed with the atoms of other elements such as Phosphorus (P), Boron (B) as Primary Dopants and Carbon (C), Magnesium (Mg), Titanium (Ti) etc. as secondaries. This mixing also known as adding "Impurities" to the Silicon Cell. Adding impurities will add extra electrons to the Silicon Cell and increase the density of electrons in the cell. Hence, the Silicon cell will be capable to capture Solar Energy and convert it into the electricity [10]

Since the Solar Panel produces the Electricity in the form of Direct Current (DC) it cannot be used to drive an Induction Motor (Single Phase/Three Phase) based Water Pump. Water Pumps with Induction Motors are being used in the proposed water pocket solutions. Hence, the same DC current from the Solar Panel should be converted into Alternating Current (AC) to drive the above-mentioned pump. Solar Pump Driver does that function while satisfaction of Driven and protection requirements of the motor. The specific requirements will be calculated, discussed, and selected under the Design and Selection of the Solar Pump Driver [2].

D. Design Calculations and Selection of Solar Photovoltaic Panel

As mentioned above, photovoltaic panel of this system plays an important role in this system. Hence, selection of the same shall be done carefully in order to achieve a better output for the system. Proper selection of the Photovoltaic panel provides following benefits [3].

1. Provides the best contribution for the operation of the system.
2. Optimization of the system such as space optimization for the panel system.
3. Reduction of unnecessary costs.
4. Warrants an enhanced design life of the system.

Hence, it confirms that the proper selection of the solar panel is essential for the effectiveness of the design. Therefore, the selection shall be done after a proper design calculation and based on its results [1].

In prior to carry out the calculations, it is required to model the equivalent circuit of a solar cell. Following fig. 4 shows the equivalent circuit of the same.

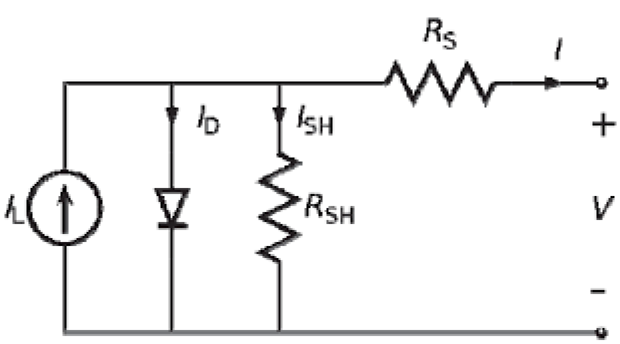

Fig. 4. Equivalent Circuit of a Solar Cell

Here,
R_s = Series Resistance in the Solar Cell (Ω)
$\boldsymbol{R_{SH}}$ = Shunt Resistance (Ω) [4].

From Fig. 4, following equation can be obtained,

$$\boldsymbol{I = I_L - I_D - I_{SH}} \quad \ldots\ldots\ldots\ldots(1)$$

But the current across the Diode (I_D) can be given as follows

$$I_D = I_O\left[\exp\left(\frac{qV_O}{nkT}\right) - 1\right] \ldots\ldots\ldots.(2)$$

When (2) substitutes to (1), then,

$$\boldsymbol{I = I_L - I_O\left[\exp\left(\frac{qV_O}{nkT}\right) - 1\right] - I_{SH}} \ldots\ldots..(3)$$

Where,

I = Output Current (A)
I_L = Photo Generated Current (A)
I_D = Diode Current (A)
I_{SH}= Shunt Current (A)
I_O = Reverse Saturation Current (A)
n = Diode Ideality Factor (n=1.2 will be considered for these calculations.)
q = Elementary charge of an electron (1.602×10^{-19}C)
k = Boltzmann Constant (1.380×10^{-23} JK^{-1})
T = Absolute Temperature (K)
V_O= Output Voltage (V)

Here we can neglect the shunt current $\boldsymbol{I_{SH}}$ as we assume that the same is in a smaller value compared to the other parameters of the equation. As per our assumption, the shunt current $\boldsymbol{I_{SH}}$ became smaller due to large shunt resistance $\boldsymbol{R_{SH}}$ in the solar cell. Hence, we further assume that the respective solar cell is free from following matters [3].

1. Manufacturing defects
2. Physical damages done by external parties.

It is important to note that $\boldsymbol{R_{SH}}$ become lower at above mentioned matters and it affects to the output of the solar cell. With that, we can re arrange the calculation as,

$$\boldsymbol{I = I_L - I_O\left[\exp\left(\frac{qV_O}{nkT}\right) - 1\right]} \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

At the Short-circuited conditions, $\boldsymbol{V_O}$ becomes 0. Hence, we can rearrange Equation 4 as follows by substituting 0 to $\boldsymbol{V_O}$. Then,

$$\boldsymbol{I_{SC} = I_L - I_O[\exp(0) - 1]}$$

Where,
$\boldsymbol{I_{SC}}$ = Short-Circuited Current of the Solar Cell

Then,

$$\boldsymbol{I_{SC} = I_L} \ldots\ldots\ldots..(5)$$

Hence, Short-Circuited Current of the Solar Cell $\boldsymbol{I_{SC}}$ becomes approximately equivalent to Photo-Generated Current $\boldsymbol{I_L}$ as per equation no. 05.

Here, we can derive an equation for Open-Circuited Volage (V_{OC}) from equation no.02. However, the output current I becomes 0 at the same condition. The equation can be rearranged as follows.

$$0 = I_L - I_O \left[\exp\left(\frac{qV_{OC}}{nkT}\right) - 1\right]$$

Then,

$$V_{OC} = \frac{nkT}{q} \ln\left(\frac{I_L}{I_O} + 1\right) \ldots\ldots\ldots\ldots(6)$$

Short-Circuited Current (I_{SC}) and Open-Circuited Voltage (V_{OC})are important parameters in designing and selection of a Solar PV panel as the mentioned parameters are extremely useful in designing the protections of the solar power system. However, to select the adequate Solar PV panel system required for this operation, it is essential to consider the environmental factors, especially the Solar Irradiance in the District where the system is going to be implemented. Best efficiency can be obtained from the designed system unless of considering those environmental factors pertaining the relevant location.

All the required electrical parameters to select the Solar PV panel (such as I_{SC}, V_{OC} etc.) will be calculated based on the Solar Irradiance of the relevant location. Hence, Global Horizontal Irradiance (GHI) of the location will be used. Global Horizontal Irradiance is total solar irradiance effect on the horizontal surface. It is the sum of Direct Normal Irradiance (DNI), Diffuse Horizontal Irradiance and Ground Reflected Radiation. Following fig. 5 shows how GHI incidents on a Solar PV Panel [3].

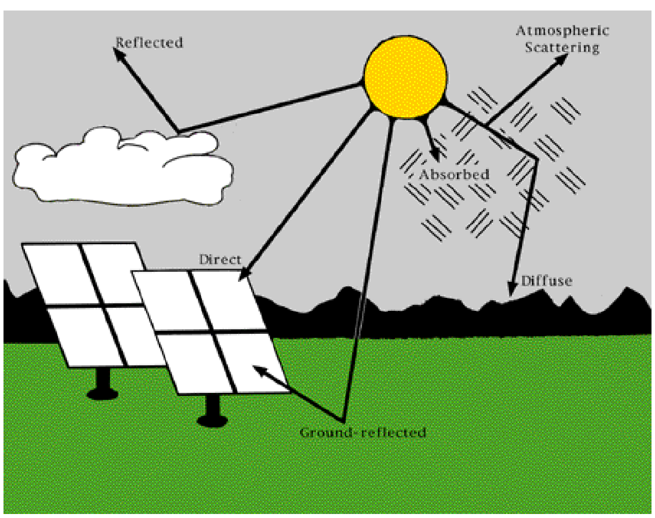

Fig. 5. How Global Horizontal Irradiance incident on a PV Solar Panel

The proposed Solar-Power Driven Water Pumping system is planning to implement in Boyagene, Kurunegala District. Hence, GHI range of Kurunegala District shall be used for the design calculations. Therefore, we hereby use Annual Global Horizontal Irradiance map published by Sri Lanka Sustainable Authority (SLSEA). Fig. 6 shows same as follows.[1]

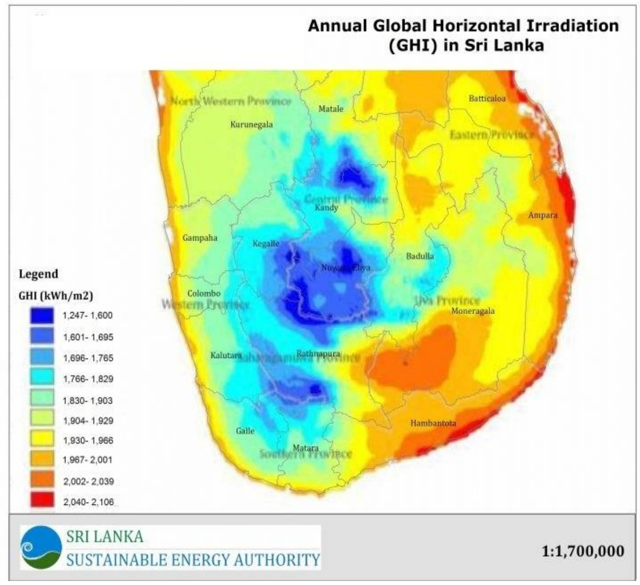

Fig. 6. Global Horizontal Map (GHI) for Sri Lanka

As per the Annual GHI map of Sri Lanka in fig. 6, the GHI of Boyagane area of Kurunegala District is 1904kWh/m^2 – 1929kWh/ m^2. Required I_{SC} and V_{OC} ranges will be calculated according to the above Irradiance data.

It is found that Short-Circuit Current Density (J_{SC}) has a relationship Solar Irradiance (or GHI). This can be derived as follows [2].

$$J_{SC} = -q \int_{\lambda 1}^{\lambda 2} EQE(\lambda)\, \phi\, d\lambda \ldots..(7)$$

Where,

$EQE(\lambda)$ = External Quantum Efficiency (%) of the Solar Cell
ϕ = Spectral Photon Flux
λ_1 = Lower limit of the Wavelength of the Visible light (m)
λ_2 = Upper limit of the Wavelength of the Visible light (m)

Here the External Quantum Efficiency (EQE) is the ratio of the charged carriers collected by the solar cell to the number of photons of a given energy of the outside of solar cell (incident Photons). Here, the Energy of the Visible Light from Sun is a consistent of Photons. Since the energy of a Photon is given by the Planck’s equation, above mentioned

parameters can be mentioned in terms of the variables of the Planck's equation as follows.
However, the Power Density (***H***) can be stated in terms of Planck's equation. Here, Power Density ***H*** is equivalent to Global Horizontal Irradiance **(GHI)** [1].

Therefore, we can mention the Planck's equation as follows.

$$E_{\lambda} = h\upsilon \ldots (8)$$

However,

$$C = f\lambda \ldots .(9)$$

Since,

$$\upsilon = f$$

from (9) to (8)

$$E_{\lambda} = \frac{hC}{\lambda} \ldots\ldots..(10)$$

Substituting equation (10) to (11)

$$H\left(\frac{W}{m^2}\right) = \phi E_{\lambda} = \phi \frac{hC}{\lambda} \ldots\ldots\ldots\ldots..(11)$$

Where,

H = Power Density / GHI (W/m^2)
E_{λ}= Energy of a Photon (J)
h = Planck's constant (6.626×10^{-34} J.s)
C = Velocity of the Light (3×10^8 m/s)
υ = Frequency (Hz)
f = Frequency (Hz)

From Equation (11), Spectral Photon Flux can be denoted as

$$\phi = \frac{H\lambda}{hC} \ldots\ldots\ldots(12)$$

Further, External Quantum Efficiency [$EQE(\lambda)$] can be denoted as,

$$EQE(\lambda) = \frac{hC}{q\lambda} R \ \ldots\ldots(13)$$

Where,

R **=** Spectral Response (A/W) of a Solar Cell

The Spectral Response ***R*** is the ratio between the generated current by the Solar cell to power incident to the solar cell. The value of Spectral Response may take a value between 0 to 1. Normally, ***R*** becomes 1 in the ideal condition of the Solar Cell. However, numerous researches have been conducted to take the value of ***R*** to one and it was succeeded. Scientists and Engineers have taken its value approximately to 1 by using following methods.

1. Introducing PERC (Passivated Emitter and Rear Cell) technology to modern Solar Panels.
2. Introducing Impurities with better Electron Density to Si Cell.

We assume that the Spectral Response ***R*** of the selected panel is approximately equals to 1 because above PERC technology has been introduced for most of the modern Solar Panels available in the market [1].

Hence substituting equation (13) to equation (7),

$$J_{SC} = -q \int_{\lambda 1}^{\lambda 2} \frac{H}{q} d\lambda$$

$$|J_{SC}| = |-H[\lambda_2 - \lambda_1]|$$

$$|J_{SC}| = H[\lambda_2 - \lambda_1] \ \ldots\ldots(14)$$

As per the GHI map mentioned in Fig.7, the lower limit of the ***H*** is $1904 kWh/m^2$. But the same should be converted into W/m^2 in order to be suit for equation 14. Hence, by considering prevalence duration of the sunlight as 9 hours, then [3],

$$H(W/m^2) = (1904 / 9 \text{ hrs}) * 1000$$
$$= 211.56 \times 10^3 \ W/m^2$$

Considering the range of the Wavelength of Visible Sunlight as **400nm~750nm** and substituting for equation 14,

$$J_{SC} = 211.56 \times 10^3 [750\text{-}400] \times 10^{-9}$$
$$J_{SC} = 0.074 \ A\ m^{-2}$$

However, a latest Polycrystalline PV panel consists with 72 cells and standard area of the panel is $1.83\ m^2$ .Therefore according to the following equation

$$I_{SC} = |J_{SC}|.A \ \ldots\ldots(15)$$

$I_{SC,\ Total\ 1}$ = 0.074 x 72 x 1.83 = 9.75A

Substituting value of $I_{SC,\ Total\ 1}$ to above equation no. (5). Then

$$I_{L1} = 9.75A$$

Since Reverse Saturation Current (A) I_o of a Silicon Solar Cell is equal to **$1 \times 10^{-12}\ A/cm^2$** then, Reverse Saturation current of a Silicon Solar Cell based solar panel is, (Panel's area is 1.83 $m^{2)}$

$\boldsymbol{I_o}$ **=** $1 \times 10^{-12} \times 10^{4} \times 1.83$
$= 1.83 \times 10^{-8}$ A

With the above results we can evaluate Open-Circuit Voltage (**V_{OC}**) of the solar cell. Hence, from equation (6),

$V_{OC} = [(1.2 \times 1.380 \times 10^{-23} x304)/1.602 \times 10^{-19}] \ln[(9.75/1.83 \times 10^{-8}) +1]$

$= 0.6314$ V

Here we considered Ideality Factor ***(n)*** as 1.2 for Silicon based Solar Cells. And the average temperature of the Kurunegala District as 31 ºC . Further, latest Polycrystalline PV panel consists with 72 cells as mentioned above [2],

$V_{OC} = 0.6314 \times 72$
$= 45.46$ V

Please note that here we considered that the Silicon based Solar Cells have been connected in Series inside of the panel. Now we consider the Upper limit of ***H*** as per the GHI map mentioned in Fig.7. As per the map the upper limit of the Power Density is **1926 kWh/m²**. But the same should be converted into W/ m^2 as above in order to be suit for equation 14. Hence, by considering prevalence duration of the sunlight as 9 hours, then [1],

$$H(W/m^2) = (1926 /9 \text{ hrs}) * 1000 = 214 \times 10^3 \text{ W/m}^2$$

Considering the range of the Wavelength of Visible Sunlight as **400nm~750nm** and substituting for equation 14,

$$J_{SC} = 214 \times 10^3 [750-400] \times 10^{-9}$$
$$J_{SC} = 0.0749 \text{ A m}^{-2}$$

Considering the equation (15) again, we can get

$I_{SC, Total\ 2} = 0.0749 \times 72 \times 1.83 = 9.869$A

Substituting value of $I_{SC, Total\ 2}$ to above equation no. (5). Then

$$I_{L2} = 9.869\text{A}$$

The value for $\boldsymbol{I_o}$ for the solar panel has been derived previously, hence,

$\boldsymbol{I_o}$ **=** 1.83×10^{-8} A

Open-Circuit Voltage (**V_{OC}**) of the solar cell can be found using above results. Hence, from equation (6),

$V_{OC} = [(1.2 \times 1.380 \times 10^{-23} x304)/1.602 \times 10^{-19}] \ln[(9.869/1.83 \times 10^{-8}) +1]$

$= 0.6318$ V

As above, considering that the Polycrystalline PV panel consists with 72 cells, we can calculate the open circuit voltage (**V_{OC}**)

$V_{OC} = 0.6318 \times 72$
$= 45.49$ V

As above, here we considered that the Silicon based Solar Cells have been connected in Series inside of the panel. With that, the obtained value was multiplied by the number of cells in the PV panel.

It is identical that the obtained values for V_{OC} and I_{SC} are same in both lower and upper limits of the Power Density/GHI for Boyagane area, Kurunegala District. Hence, following values will be considered further to select the PV panel.

$V_{OC} = 45.49$V

$I_{SC} = 9.869$ A

Apart from the above, it is essential to obtain the Voltage and Current parameters at the Maximum Power Point to select the Photovoltaic panel. Maximum Power Point Tracking (MPPT) method is used maximize the power extraction at any time of operation. Hence, Voltages and Currents of PV panel at Maximum Power Point is essential to select the suitable Grid-Connected Solar Inverter, Off-Grid Solar Inverter or Solar Pump Driver. Further, same voltages and currents are useful to size the switchgears and surge arrestors required to implement the solar system.

Electrical parameters at the Maximum Power Point can be mentioned as follows [2].

P_{MPP} **=** Power in Maximum Power Point (Wp) / Maximum Power (***P_{MAX}***)
V_{MPP} **=** Voltage in Maximum Power Point (V)
I_{MPP} **=** Current in Maximum Power Point (A)

Above parameters can be found through I-V curves and P-V curves. V_{MPP} and I_{MPP} values can be tracked in reference with maximum power point on the P-V curve. Here we use above equation no.04 to plot the I-V curve and P-V curve will be derived with the multiplication of Current and Voltage Values. **Table I** shows the values obtained and Fig. 7 shows I-V and P-V graphs plotted accordingly [2].

TABLE I. DATA TO BE USED TO PLOT I-V AND P-V CURVES

Output Voltage (V)	Output Current (A)	Power (W) [Output Voltage x Output Current]
0	9.869	0
5	9.865	49.325
10	9.865	98.65
15	9.865	147.975
20	9.865	197.3
25	9.855	246.375
30	9.84	295.2
35	9.656	337.96
40	9.153	366.12
45	6.653	299.385
50	0	0

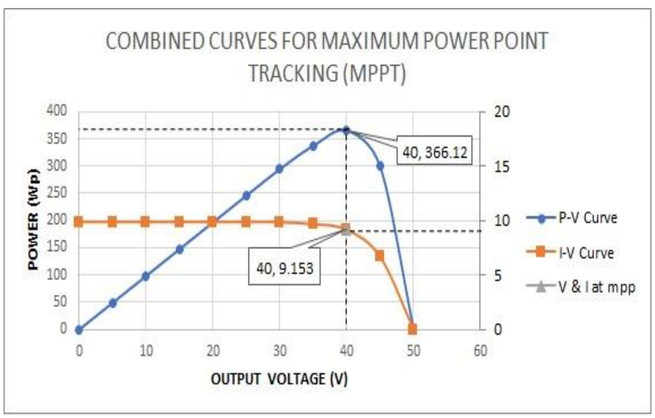

Fig. 7. MPPT curves (I-V & P-V Curves)

As per fig. 7, P_{MPP} is 366.12W. At the P_{MPP} following values also can be obtained through the same curve.

$$V_{MPP} = 40V$$
$$I_{MPP} = 9.153A$$

And, P_{MPP} value is used to calculate the number of PV panels are required to drive the motor of Solar Power Driven Water Pumping system for Boyagane Pocket Solution [2].

Therefore, we can calculate the number of panels required to drive the pump motor as follows. However, the obtained value for P_{MPP} through the above curves in Fig. 7, should be matched with the existing panel capacities in the market. Hence, the following number of panels can be differed based on the capacity of the selected PV Panel. However,

P_{MPP} = 366.12 Wp
Number of Panels = (2kW x 1000) / P_{MPP}
= 5.5

Since we need to state a number of PV panels, above value should be **6 numbers.**

Hence, obtained results of technical specifications after the design calculations for PV panel to can be mentioned in following **Table II.** PV Panel can be selected accordingly [1].

TABLE II. CALCULATED PARAMETERS FOR PV PANEL

Parameter	Value	Value to be used for the selection after resolution of 6%
Power Output (Wp)	366.12	388.09
Nominal Power Voltage (V_{MPP}) (V)	40	42.4
Nominal Power Current (I_{MPP}) (A)	9.153	9.7
Open Circuit Voltage (V_{oc}) (V)	45.49	48.22
Short Circuit Voltage (I_{SC}) (A)	9.869	10.46

It should be noted that a 6% resolution to be added for the designed values in order to make easy in selection. This resolution is added as per the panel manufacturer's requirements. Nearest values to the designed and resolution added values to be used for the selection [3].

E. *Selection Calculations and parameters of Solar Pump Driver*

Solar Pump Driver is the other main part which is used to drive the 2kW motor of the pump. Following requirements shall be highlighted in prior to conduct the selection calculations of the Solar Pump Driver [4].

1. Duty power supply of the selected Solar Pump Driver should be Solar Electricity while standby power supply should be the CEB power supply. This requirement is necessary to operate the pump at night times where the solar electricity is not available.
2. Variable Frequency Driving Function should be available in the Solar Pump Driver.
3. Operational monitoring and controlling functions and interfaces should be available with the Solar Power Driver. In other terms, the same should be capable to connect to a SCADA system (Supervisory Control and Data Acquisition)[5].

Apart from the main requirements, following electrical parameters to calculated in order to select the Solar Pump Driver.[3]

1. Input DC MPPT Voltage (***$V_{MPPT,Rated}$***)
2. Rated Current
3. Input Open-Circuit Voltage (***$V_{OC,Controller}$***)
4. MPPT Efficiency

Following parameters should be known to select the Solar Pump Drive.[4]

1. Power Rating of the pump motor
2. Input Voltage of the pump motor
3. Number of input phases of the motor
4. Motor Type

Power rating of the pump motor is being used for Boyagane is 2kW. Input voltage for the same pump is 230V AC as 2kW pump motors are commonly available in Single Phase electrical input in the market. Motor type shall be Induction type [4].

Now we shall calculate the parameters mentioned above.

1. Input DC MPPT Voltage

As we found the MPPT Voltage of the panel the curves mentioned in Fig. 7, then [2],

Input DC MPPT Voltage = Nominal Power Voltage (V_{MPP}) (V) * Number of Panels used in the system …..(16)

Input DC MPPT Voltage ($V_{MPPT,Rated}$) = 42.4 * 6 = 254.4V
In other words, Input DC MPPT Voltage can also be defined as the "Rated Input Voltage" of the Solar Pump Driver [1].

1. Rated Current (I_{Rated})

Rated current of the Solar Pump Driver is equivalent for the Maximum Power Point Tracking Current of the Panel Array. Hence, [2]

$$I_{Rated} = I_{MPPT} \;\ldots\ldots(17)$$

$$I_{Rated} = 9.7\text{ A}$$

2. Input Open-Circuit Voltage ($V_{OC, Controller}$)

Here, the Open-Circuit Voltage of the Solar Pump Controller is equivalent to the Total Open Circuit Voltage of the panel array. Then,

$$V_{OC,\ Controller} = V_{OC} * \text{Number of Panels in the Array} \ldots.(18)$$

$$= 48.22\text{V} * 6$$
$$= 289.32\text{ V}$$

3. MPPT Efficiency (%)

MPPT efficiency is the percentage value of the ratio between input DC power of the PV array at the maximum power point and output AC power. Therefore [3],

$$\eta_{MPPT} = \frac{P_{OUT,AC}}{P_{MPP} * N} * 100\% \ldots\ldots..(19)$$

Where,

η_{MPPT} = MPPT Efficiency (%)
N = Number of Panels in the Array
$P_{OUT,AC}$ = Output Power (AC) in Watts

From the Equation 19,

η_{MPPT} = [2000W/ (366.12 * 6)] * 100%

= 91.04%

Hence, the calculated and referenced parameters can be summarized as follows in Table III to carry out the selection of Solar Pump Driver [4].

TABLE III. CALCULATED PARAMETERS OF SOLAR PUMP CONTROLLER

Parameter	Value
Rated Power (kW)	**2**
Number of Output Phases	**Single Phase (Live & Neutral)**
Output Voltage	**230 V AC**
Input DC MPPT Voltage/ Rated Input Voltage $V_{MPPT,Rated}$)(V)	**254.4**
Rated Current (I_{Rated}) (A)	**9.153**
Input Open-Circuit Voltage ($V_{OC, Controller}$)	**289.32**
MPPT Efficiency (%)	**91.04**

Apart from the calculated electrical parameters mentioned in above Table III, the availability of following features in Solar Pump Driver are also to be verified in prior to select the same [4].

1. Dry Run Protection (Under Load Protection)
2. High Voltage Surge Protection
3. Protection from Low input voltage
4. Open Motor Circuit Protection
5. Short Circuit Protection
6. Overheat Protection
7. Earth Fault Protection
8. Phase Failure Protection (Specially for 3Ph Motors)

3. FURTHER MODIFICATIONS TO THE DESIGNED SOLAR POWER DRIVEN WATER PUMPING SYSTEM

F. Reduction of further Electricity costs incurred during the night times.

Designed system operates with the CEB electricity supply in the night times since Solar power is not available to run the Solar Pump Driver. Some water pocket solutions of this project have been designed without an overhead tank as shown in Fig. 2. This situation leads to a continuous operation of the water pump system and considerable electricity cost is being generated due to it. Hence, construction of overhead tanks for such systems will be encouraged to avoid the above-mentioned wastage. With that, the pump system can be driven for a specific interval, until the overhead tank is filled completely.

G. Integration and Optimization of Sensor Data Acquisition to the Solar Pump Driver

It has been planned to use Remote Terminal Units (RTU) at pocket solution pump houses to maintain the communication between the Polgahawela Water Treatment Plant SCADA and the same pump houses. GSM/GPRS SIM can be placed in RTUs and all the detectors/sensors (Pressure, Flow etc.) are connected to the same. The designed Solar Pump Drive will be modified so as to place a GSM / GPRS SIM inside of it and patching interfaces will be increased to interface external detectors, sensors and alarms to the same driver. Assistance also will be taken from the Solar Driver manufacturer with this regard to carry forward.
With the above action, additional cost to be incurred to the RTU will be reduced and communication errors/delays will also be avoided since a single system accommodates all the above requirements [6].

4. CONCLUSION

The designed system is a new movement in the renewable energy sector in Sri Lanka and a pessimistic solution for National Water Supply & Drainage Board at its energy saving and management activities. Further, this is a complete solution for NWSDB pump houses which are in remote areas, and which have CEB power supply issues such as continuous power failures.

This design has been proposed for the proposed for the Boyagane Water Pocket Solution pump house of Polgahawela, Pothuhera, Alawwa Integrated Water Supply Project. However, the author wishes to expand this solution to the other pocket solution pump houses in the same project too.

Further, this solution makes an easy integration of the water supply monitoring instrumentation in the relevant premises and to the SCADA system of the Polgahawela Water Treatment Plant. It is because of the in-built communication interfaces available in the Solar Pump Driver. In the other hand, Solar Pump Drivers such as Schneider make drivers will give the facility to monitor and control the pump system condition directly through a static IP address without any involvement of the SCADA system. Hence, this design provides a total integrated solution to the NWSDB not only from Electrical discipline but from Instrumentation discipline too.

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REFERENCES

[1] Markvart, Tomas, ed. (July 2000). Solar electricity (2nd ed.). Wiley. pp. 298. ISBN 978-0-471-98852-6.

[2] Poponi, Daniele (April 2003). "Analysis of diffusion paths for photovoltaic technology based on experience curves". Solar Energy. **74** (4):331–340.

[3] Perlin, John (1999). From space to Earth: the story of solar electricity. Earthscan. p. 50. ISBN 978-0-937948-14-9.

[4] J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.

[5] Stuart A. Boyer, "SCADA: Supervisory Control And Data Acquisition 4th Edition,"Published: Dec 2018

[6] Frederick A. Meier, and Clifford A. Meier, " Instrumentation and Control Systems Documentation-2nd Edition,"Published: Aug 2015