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Battery Driven Walk-Behind Rice Seedling Transplanter with Solar and Piezoelectric Regenerative Power Inputs

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Abstract:

Rice seedling transplanters are used by farmers to have better planting operational efficiency; to aid in challenges in labor scarcity and also to alleviate physical health issues that is related to manual rice planting. Philippines is an agricultural country with rice as its staple food, we have 34% of our agriculture land as rice paddies. Although we have a large area for rice planting, more than 50% of farm holdings is under one hectare. Purchase of large and expensive engine driven rice transplanters can be deemed unnecessary by local farmers. This study aims to show the prospect of replacing a gasoline fueled engine with a lead acid battery – DC Motor set up and the influence of adding STP010-12Solar panels and Piezoelectric array regenerative inputs. By computing and comparing power input and output it was observed that the solar panel can extend battery life to a hypothetical time of about eight (8) minutes as compared to using the battery alone; while the piezoelectric array can further extend it by one (1) minute. With the battery driven equipment's compact structure it will be more suitable for small scaled rice farmers use.

Keywords — **Walk-Behind Rice Transplanter, Lead Acid Battery, Solar Power, Piezoelectric**

I. INTRODUCTION

This Philippines is the 9th largest rice producer in the world [1]. Even if rice production dropped from 3.96 million to 3.71 million from April-June of 2015 to 2016. Likewise, harvest area contracted from 914,000 hectares to 848, 000 hectares. Rice paddies still occupies the largest agricultural area, an average of 4,469,000 hectares, accounting to 34% of the total agricultural land of the Philippines [2].

Across South Asia, labour scarcity is a major problem and there is a need to explore methods for rice planting that require less labour but does not lessen the time for transplanting [3]. The use of a mechanical transplanter is one alternative to address this issue.

There are already modern designs with different brands and models of rice transplanters that are available in the market. Mainly, there are two types of rice transplanters i.e., riding and walking type. Riding type is engine driven and is operated as an agricultural vehicle. It can usually transplant six lines in one pass. On the other hand, walking type is either engine or manually driven equipment and the operator walks behind the equipment to manoeuvre it around the rice paddy. It can usually transplant four lines maximum in one pass.

In the Philippines, over 50% of the farm holdings is under one hectare and the average area of farm parcel with temporary crops is 0.912 hectare [2]. Purchase of a self-propelled riding type or engine driven walk-behind rice seedling transplanter with prices ranging from P500,000 to P1, 300, 000 can be deemed unnecessary and of high cost by local farmers.

The walk-behind type of transplanters are best in area under or equal to a hectare. But, the manually operated walk-behind type have a low operation efficiency of 0.2 ha/day.

This study aims to investigate the performance of a walk-behind transplanter which can achieve the operation efficiency of an internal combustion engine driven transplanter, but, instead is composed of a battery-DC motor set up with regenerative power inputs.

II. SYSTEM DESCRIPTION

The battery driven walk-behind 4-row rice seedling transplanter was modelled after NSP-4W Kubota gasoline engine driven walk-behind rice transplanter.

The internal combustion engine was replaced by a battery-dc motor system with solar and piezoelectric power regenerative inputs.

There are five (5) maintenance-free lead acid batteries used in the equipment coupled to DC Motors. To lengthen the battery life while in cycle use, four (4) STP010-12 solar panels and an array of piezoelectric components were added. Shown in Fig. 1 is the regenerative system block diagram. Note that two panels consist every solar panel block in the diagram.

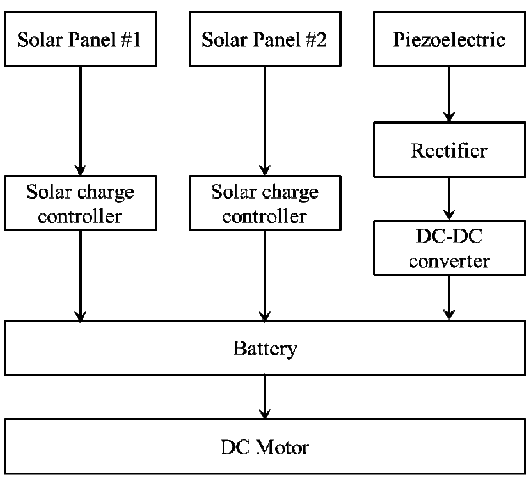

Fig. 1 Regenerative Power Input System Block Diagram

III. SYSTEM COMPONENTS

1. Maintenance-free Lead Acid Battery - Multi-functional for both cycle and standby use No-spill design. Can be used in any orientation. The battery specification is listed in Table 1.

Table 1: Battery Specifications

S.I. No.	Description	Measure
1	Model	ES5-12
2	Type	Lead Acid
3	Nominal Voltage	12 V
4	Nominal Capacity 20 hour rate (0.25A to 10.50V)	5Ah
5	Weight	Approx. 4.18 lbs (1.9kg)
6	Internal Resistance (at 1KHz)	Approx. 19mΩ
7	Operating Temperature Range	-15°C to 40°C
8	Charging Method (Cycle Use)	Charging Voltage 14.4 to 15.0V Coefficient -5.0mv/°C/Cell Maximum Charging Current: 1.5A

2. Solar Panel - The STP010-12 is a 10 watt, 12 volt solar panel, and will provide enough power to trickle charge a 12V deep cycle battery. Listed in Table 2 are the Solar Panel specifications.

Table 2: Solar Panel Specifications

S.I. No.	Description	Measure
1	Model	STP010-12
2	Cells	Multi crystal silicon
3	No. of Cells & Connections	36 Cells in Series
4	Open Circuit Voltage -Voc	21.6 V
5	Maximum Power Voltage - Vmp	17.2 V
6	Short Circuit Current - Isc	0.64 A
7	Maximum Power Current - Imp	0.58 A
8	Weight	1.5 kg
9	Dimensions	310 x 368 x 18 mm

3. Solar charge controller - limits the rate at which electric current is added to or drawn from electric batteries [4]. It prevents overcharging and may protect against overvoltage, which can reduce battery performance or lifespan, and may pose a safety risk. It may also prevent completely draining ("deep discharging") a battery, or perform controlled discharges, depending on the battery technology, to protect battery life [5]. Listed in Table 3 is the Suoer Solar Charge Controller Specifications.

Table 3: Solar Charge Controller Specifications

S.I. No.	Description	Measure
1	Model	ST-G1220
2	Rated charging power	240W
3	Charging current rating	20A
4	Battery voltage	12V/24V
5	Charging voltage	13.6V/27.2V
6	Float charging voltage	13.8V/27.6V
7	Discharge cut-off voltage	10.5V/21V
8	Battery over-voltage protection	17V/34V
9	Size(mm)	167x124x50

4. Piezoelectric Sensor - a device that uses the piezoelectric effect, to measure changes in pressure, acceleration, temperature, strain, or force by converting them to an electrical charge [6].

The piezoelectric array was patterned after a published study entitled, “Vibration Energy Harvesting Using a Piezoelectric Circular Diaphragm Array” shown in Fig. 2.

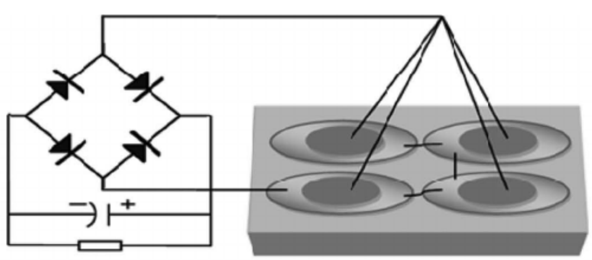

Fig. 2 Schematic diagram of energy harvesting circuits in parallel connection through a single rectifier circuit

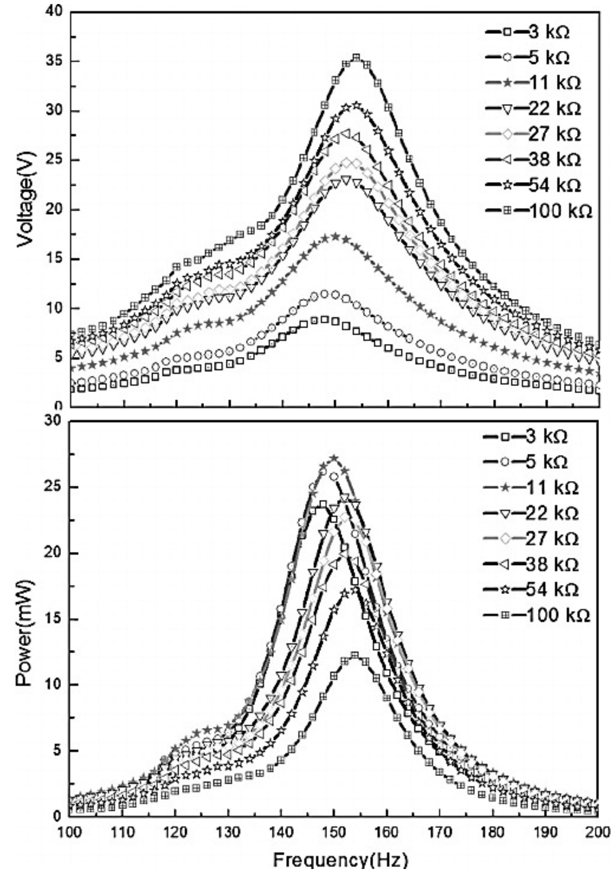

Fig. 3 Output voltage and power of a piezoelectric diaphragm array in parallel connection through a single rectifier circuit.

Fig. 3 shows the results of the array in parallel connection through a single rectifier circuit as a function of the frequency with varied resistive loads. The results were measured as a function of load resistance with a fixed pre-stress condition (0.8 N) under a vibration acceleration of 9.8 m/s2. A maximal output power of about 24.4 mW can be obtained from the array at the operating frequency of 150 Hz across a resistive load of 11 kΩ. [7].

Using eight (8) plates of the same design to be the tranplanster piezoelectric array, a 0.0972 kW-Hr power can be generated.

IV. COMPONENTS RATINGS CALCULATIONS

1. Power Requirement per Hectare

Since the equipment was modelled after a gasoline engine driven transplanter, it is assumed that it has equivalent power requirement per hectare of operation.

Listed on Table 5 is the gasoline engine specifications of the transplanter.

Table 5: Kubota TransplanterEngine Specifications

S.I. No.	Description	Measure
1	Model	MZ175
2	Type	Reduction Type
3	Fuel Efficiency	2.0 - 4.7 kg/ha
4	Fuel Consumption	300 g/kW-Hr

The required power in kW-hr per hectare is computed using Eq. (1)

$$\text{kW-Hr per Ha} = \frac{Fuel\ Efficiency}{Fuel\ Consumption} \qquad \text{Eq. (1)}$$

kW-Hr per Ha is 6.667 - 15.667 kW-Hr/ha

The nominal power requirement for the gasoline engine is at 6.667 kW-Hr/ha.

2. Number of Batteries Required

Table 6: Battery Efficiency Estimates

S.I. No.	Description	Measure
1	Battery Average Efficiency	0.88
2	Inverter Average Efficiency	0.92
3	Wiring Distribution Efficiency	0.98

Battery Efficiency Estimates were taken from a Solar Sizer Spreadsheet from Solarray Techguide site [8]

For a 20 hr nominal capacity battery with consideration of the efficiency estimates the total power generated by the battery is 1512.463 Watt-Hr, computed using Eq. (2)

$$\text{Battery kW-Hr Rating} = \frac{Ah\ x\ Nominal\ Voltage\ x\ Hrs}{\prod(Battery\ Efficiency)}$$

Eq (2)

Where:
Ah is the Amp-hr of the nominal capacity

Table 7: No. of Batteries vs kW-Hr Produced

No. of Batteries	kW-Hr
1	1.512
2	3.024
3	4.536
4	6.048
5	7.560

The nominal power requirement of the gasoline engine on one hectare of operation is 6.667 kW-Hr/ha.

Table 7 shows the total kW-Hr for a given number of batteries. Since it is assumed that the battery driven has equivalent power requirement with that of the gasoline engine, which is 6.667 kW-Hr/ha; five (5) batteries was chosen, as its kW-Hr rating is greater than the minimum power required per hectare.

3. Solar Panel Power Rating Estimates

Solar Panel Losses tabulated in Table 8 and solar panel parameters tabulated in Table 9 were acquired from Solarray Solar Sizing Estimation [8].

Table 8: Solar Panel Losses

S.I. No.	Description	Measure
1	Inverter losses (6% to 15 %)	8%
2	Temperature losses (5% to 15%)	8%
3	Cables losses (1 to 3 %)	2%
4	Shadings 0 % to 40% (depends of site)	1%
5	Losses weak irradiation 3% to 7%	3%
6	Losses due to dust (2%)	2%

Table 9: Solar Panel Power Rating Computational Parameters

S.I. No.	Description	Measure
1	Total Solar Panel Area (m^2), A	0.11408
2	Number of Panels, n	4
3	Solar panel yield (%), r	0.20
4	Performance ratio (coefficient for losses) (range between 0.9 and 0.5), PR	0.78
5	Annual average irradiation on tilted panels (shadings not included, $kWh/m^2.an$), H	1,000

The performance ratio or coefficient of losses was computed using Eq (3).

$$\text{Performance Ratio (PR)} = \prod(1 - Loss) \qquad \text{Eq (3)}$$

Total Energy in kW-Hr of five (5) solar panels was computed using Eq (4).

$$\text{Total Energy} = (A \text{ x } r \text{ x } PR \text{ x } H \text{ x } n)\left(\frac{1\ year}{365\ days}\right) \text{Eq (4)}$$

Total Energy = 0.0829 kWh / day

4. Solar Control Charger

The rating of the charge controller was computed using Eq (5).

Solar Charge Controller Rating = Isc x Np x SF Eq (5) Solar Charge Controller Rating = 0.64A x 2 x 1.25

Solar Charge controller rating = 1.6A (minimum controller input current)

Calculating the controller load, Eq (6) was used.

Max. DC load current = Wdc / Vdc
Eq (6)

Max. DC load current = 240W/12V
Max. DC load current =20A (minimum controller output current)

The pwm charge controller that is going to be selected is the 20A charge controller.

Through this calculation, the Suoer Solar Charge Controller was chosen with specifications listed on Table 3.

V. CONCLUSION AND RECOMMENDATION

A walk-behind rice transplanter which is gasoline engine driven can be replaced with a battery-DC Motor set up that can achieve equivalent operational efficiency.

To be able to extend battery life while in cycle use it is also possible to add regenerative power input into the system. As for this study, it was proven that addition of solar panels as alternative power source extends the battery life to about a hypothetical time of 8 minutes as compared to that of using the battery alone.

The piezoelectric array extended the battery life with solar panel for a hypothetical time of about 1 minute. Given that the array consisted of eight (8) plates of piezoelectric set up operating with a single rectifier per plate, this amount of power input is small for the whole system use.

It is therefore proposed to evaluate the design of the piezoelectric array to be able to optimize its power harvesting as part of a heavy equipment that operates in cycle use.

Since the regenerative power input like the solar panel and piezoelectric have many variables to consider for proper simulation of power output, it is also proposed to have the actual simulation of the components on an electrical laboratory with calibrated testers.

Further, battery driven equipment have a compact structure compared to their internal combustion engine driven counterpart. This will then be more applicable to small scaled rice paddies and can minimize the existing status of big turning radius of large transplanter with diesel or gasoline as fuel.

If the walk-behind rice transplanter can be fully operational with a battery-DC Motor set up and with regenerative power input, this could greatly help small scaled farmers that is facing a challenge in labor scarcity.

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