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Development of a solar charged laboratory bench power supply

W A Ayara[1,1], T V Omotosho[1,2], M R Usikalu[1,3], M S J Singh[2] and W Suparta[2]

[1]Department of Physics, Covenant University, Ota, Nigeria
[2]Space Science Centre, Institute of Climate Change, Universiti Kebangsaan Malaysia, Malaysia

[*]E-mail: [1]williams.ayara@covenantuniversity.edu.ng,[2]omotosho@covenantuniversity.edu.ng, [3]moji.usikalu@covenantuniversity.edu.ng,[2]wayan@ukm.edu.my

Abstract. This product is an improvement on available DC laboratory bench power supply. It is capable of delivering low voltage Alternating Current (AC) and Direct Current (DC) to carry out basic laboratory experiment for both secondary schools and also at higher education institutions. The power supply is capable of delivering fixed DC voltages of 5V, 9V, 12V, the variable voltage of between 1.25–30V and a 12V AC voltage. Also Incorporated is a USB port that allows for charging cell phones and other mobile devices, and a dedicated 12V DC output to power 5-7 Watt LED bulb to provide illumination in the laboratory for the instructor who may need to work at night in the absence of utility power.

1. Introduction
Erratic power supply is one huge factor limiting advancement in education in the developing world especially in rural environments, taking its toll in the area of basic experiments in sciences, engineering, and technology. Electric power supply is the most important commodity for national development. With electrical energy, the people are empowered to work from the domestic level and the cottage industries, through the small-scale and medium industries to employment in the large-scale manufacturing complexes [1].

Laboratory Bench Power supply is a common electrical/electronic power unit found in laboratories. These available units have only one source of input power by which they can be put to use. Erratic mains power or the complete mains outage renders this all important laboratory power unit non-useful appliance. Hence basic laboratory experiment requiring constant low power Alternating Current (AC) or Direct Current (DC) voltages are forced to be put on hold.

The unit is designed such that the internal energy storage bank can be charged using solar energy with the help of an internal charge controller circuitry. Hence it becomes very important as it is conveniently used to meet the need of low DC and AC power requirement for basic experiments in schools located in places where there are habitual power outages or total power failure from the utility supply. As a result, the usual postponement or outright cancellation of experiments in practical classes due to power outage will be a thing of the past.

2. Basic Overview of The Entire Unit
The functionality of the device is based on regulated DC power supply (fixed and variable) in conjunction with fixed AC supply. The primary requirement considered in the design of the regulated

DC power supply are the output voltage V_{dc}, maximum current I_{max} required by the load, percentage load and line regulation [2, 3].

2.1 The Transformer and Full-wave rectifier
This is a multiple output transformer that receives an input AC mains supply voltage of between 220-230V and steps it down to lower voltages of 2x15V, 2x12V, and 2x7V all center-tapped. The AC voltage from the transformer is rectified using a full-wave rectifier made up of four P-N junction diodes to form a rectifying bridge [3] providing DC supply. Depending on the configuration of the transformer, the full-wave rectifier could give single positive, or equal positive and negative voltages that are needed by several DC operated circuits such as operational amplifiers [2, 3].

2.2 The Smoothing Circuit and Voltage Regulation
The ripples are smoothened using a low pass filter in the form of a shunt capacitor [3]. The effect of continuous charging and partial discharging causes ripples on the DC level. Hence, depth of the ripple depends on the capacity of the reservoir capacitor and also the amount of current drawn by the load. To attain better smoothing and minimize ripple, large value capacitor (1,000μF of more) is used, so that the potential difference across its terminals falls more slowly [3 - 5].

The voltage regulation stage of supply provides a stabilized DC voltage to the output interface as set by the integrated circuit regulator (IC) [4]. The regulators provide both fixed and variable output DC voltages of 5V, 9V, and 12V both of positive and negative voltages.

2.3 The Solar Panel
The sun supplies energy in the form of radiation, without which life on Earth could not exist [6]. The energy derived from the sun is converted to DC voltage by means of holes and electron exchange. Energy derived from the sun by the solar panel is used for energy storage in the battery bank. The solar panel in addition to the battery bank forms the core of this product.

2.4 The Charger, Battery bank and Inverter section
This charger is meant to deposit electrical energy in the battery bank for storage that will be useful whenever there is a power outage. As stated earlier, energy derived from the sun through the solar panel is stored in the battery bank by means of the charger. This is a charger controller that regulates the charging rate of the battery for best performance.

The battery bank is a combination of individual cells in series and parallel arrangement. Batteries are available in different sizes, voltage, amp-hour rating, vented or non-vented. The battery bank's size determines the length of time the inverter can supply AC output power. The larger the bank, the longer the inverter can run and also the longer the time to recharge [7].

The section of the inverter takes energy stored in the form of DC voltage from the battery bank and converts it to AC voltage whenever AC voltage is required when power from the mains fails.

2.5 The Mobile Device Charger and DC output for LED lighting
Mobile devices are now our everyday companion. They operate on battery and to be useful their internal power source must always be available for use. This part of the unit is reserved to supply enough energy to the battery of mobile devices like Tabs, iPod and other mobile devices whose power may be low or completely depleted.
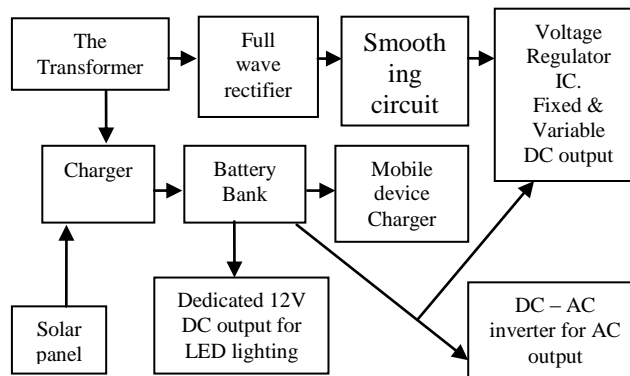
The DC output for LED lighting is a 12V DC dedicated output for lighting up light emitting diode LED. Its usefulness is harnessed mostly at night whenever there is a power outage and the instructor still intends to stay back in the laboratory.

3. Design considerations
To fully deploy the Solar Charged Laboratory Bench Power Supply; several sub-units within the entire unit were put into consideration. A few of them are considered below. It is worthy to note that the

device is low cost when compared with other commercially available DC power supply for laboratory work. Its durability is further enhanced by the fact that energy from the sun which will always be available is favorably harnessed for energy storage in the power bank.

The core focus on the design consideration is targeted at places where school laboratories are situated, having an erratic power supply or power not available for use and cost of using petrol or diesel to power generator set is high. In addition, lighting as an important factor was also considered. Therefore, the device is meant to be able to provide light at night via Light Emitting Diode (LED BULB) for any teacher or instructor who may which to work in the laboratory for some hours at night. Figure 1 shows the block diagram of a solar charged laboratory bench for a power supply.

Figure 1. Block diagram of a solar charged laboratory bench power supply

4. Hardware Considerations
The entire system consists of several units of hardware put together for its proper functioning. Areas to be considered include voltage transformation and rectification section, DC voltage smoothing section, DC voltage regulation section, solar charge controller section etc.

4.1 Voltage transformation and rectification
The transformer used is a $50H_z$ $230V_{ac}$ multiple low voltage output transformers capable of delivering 30V, 24v and 14V all centered tapped. The importance of the transformer it has the ability to completely isolate the power supply circuitry and the user from the mains hence safety is ensured. The operation of the transformer is guided by the relation:

$$\frac{N_p}{N_s} = \frac{I_s}{I_p} \tag{1}$$

The rectification of the step-down AC voltage to DC was achieved by using four (IN4007) P-N junction diodes that can handle as much as 2 Ampere.

The output of a rectifier consists of a DC component and an AC component known as the ripple. The smaller the AC component in the DC output, the better the rectifier [8]. This factor K is a ratio of the r.m.s value of the AC component to the DC component in the rectifier output. The effective r.m.s value of total load current is given by:

$$I_{rms} = \sqrt{I^2_{dc} - I^2_{ac}} \tag{2}$$

or

$$I_{ac} = \sqrt{I^2_{rms} - I^2_{dc}} \tag{3}$$

By dividing through with $I_{dc,}$ we get,

$$\frac{I_{ac}}{I_{dc}} = \frac{1}{I_{dc}}\sqrt{I^2{}_{rms} - I^2{}_{dc}} \tag{4}$$

But the ratio I_{ac}/I_{dc} is the ripple factor. The ripple factor (K) is defined as,

$$(\text{K}) = \frac{1}{I_{dc}}\sqrt{I^2{}_{rms} - I^2{}_{dc}} = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1} \tag{5}$$

In half wave rectification, $I_{rms} = I_m/2$ and $I_{dc} = I_m/\pi$, Therefore,

$$\text{K} = \frac{1}{I_{dc}}\sqrt{I^2{}_{rms} - I^2{}_{dc}} = \sqrt{\left(\frac{I_m/2}{I_m/\pi}\right)^2 - 1} \tag{6}$$

In full-wave rectification, $I_{rms} = I_m/\sqrt{2}$ and $I_{dc} = 2I_m/\pi$,   Therefore,

$$\text{K} = \frac{1}{I_{dc}}\sqrt{I^2{}_{rms} - I^2{}_{dc}} = \sqrt{\left(\frac{I_m/\sqrt{2}}{2I_m/\pi}\right)^2 - 1} \tag{7}$$

This is equal to a value of 0.48 [8], which shows that the pulsations in the output of the full-wave rectification are less than that of the half-wave. Hence the full-wave rectification is used in the design.

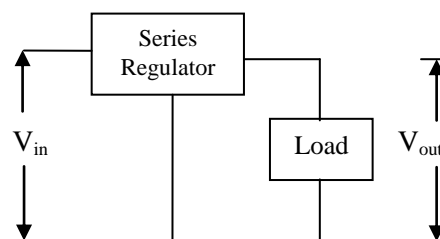*4.2 DC voltage smoothing and Dual Rail Power Supply section*
In order to clean up the residue of AC component found in the DC voltage after rectification, smoothing is carried out using appropriate filtering capacitor. In a well-designed power supply unit, the fall in output voltage is small. Before the voltage has had time to fall far, the next pulse from the other half circle arrives and the capacitor is recharged to its peak level. This continuous charging and partial discharging causes ripple on the DC level of the power supply. This ripple can be sufficiently minimized by the use of a large value capacitor [3,4].

The dual rail power supply section is responsible for providing the required DC output. The regulators LM317, LM339, and LM78xx & LM79xx series were employed to determine the + or − voltages required at the output section as shown in Figure 2. The voltages provided by this section include fixed voltages of 5, 9 and 12V and a variable voltage of 1.25-30V.

A series regulator configuration is considered for the design. Here the regulator ifs placed in series with the load [8].The variable voltage from the LM317 was determined using the formula:

$$V_{out} = 1.25V\left(1 + \frac{V_R}{R}\right) + I_{adj}V_R \tag{8}$$

where V_R is a variable resistor (pot). Note that I_{adj} is mostly controlled to less than 100μA, the error that is related to this term is negligible of many applications [9].

Figure 2. A regulator placed in series with a load

4.3 Charger and DC-AC Inverter Section

Two charger sections exist, one to provide storage energy to the battery. Battery bank comprises of two 12V banks connected in series. Hence the LM317 employed is configured such that it produces a charging voltage of 26V. The second charger which is for mobile devices is designed also using the LM317 to attain a maximum output voltage of 5V at 1A using equation (8) in both cases.

The consideration for the inverter section is to provide a 12Vac voltage in the event of mains failure. Since some experiment will require AC voltage for their operation, 12V transformer wound with a turn ratio of 1:1 connected to a low power square wave inverter is used to provide the desired $12V_{ac}$ output.

5. Testing Result and Discussion

The power supply having being calibrated was tested for voltage regulation by applying different load condition in the form of resistance to different values. Voltage regulation was carried out to determine the stability of the power supply between when the supply is on-load and when not on load. To obtain this result, two fixed voltage were set and the resistive load was connected in turn. The percentage regulation is given by the formula:

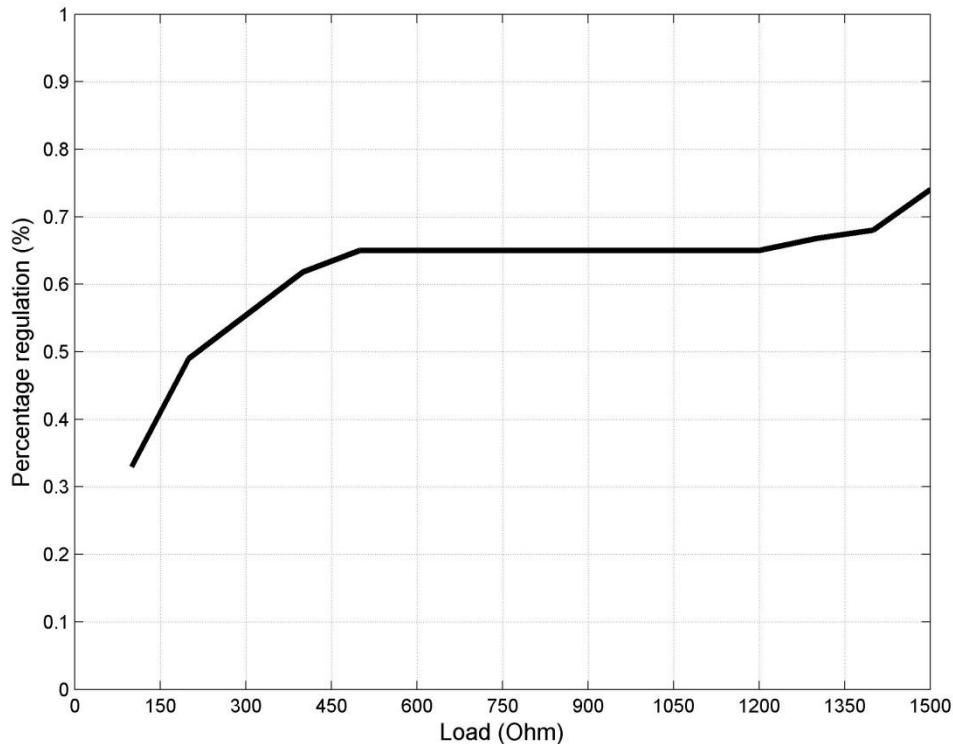$$VR = \frac{V_{NL} - V_{FL}}{V_{FL}} x100\% \tag{9}$$

where V_{NL} is the DC output at no load, and V_{FL} is the DC output at full load [8]. Table 1 shows the values obtained when a test of voltage regulation is carried out with applied load of between 100-1500Ω at a test voltage of 12.25V. A very close observation reveals that the power supply exhibit a stable voltage regulation between when a load of 400 - 1,350Ω is applied at a set voltage of 12.25V. At load exceeding 1,350Ω, voltage regulation is no longer stable. This implies that higher amount of current is being drawn. The trend of this increase is plotted in Figure 3.

Table 1. Percentage regulation at 12.25V with varying resistive load

Load (Ω)	Positive voltage (V) V_{NL}	Positive voltage (V) V_{FL}	Regulation (%)
100	12.25	12.21	0.33
200	12.25	12.19	0.49
300	12.25	12.17	0.65
400	12.25	12.17	0.65
500	12.25	12.17	0.65
600	12.25	12.17	0.65
700	12.25	12.17	0.65
800	12.25	12.17	0.65
900	12.25	12.17	0.65
1000	12.25	12.17	0.65
1100	12.25	12.17	0.65
1200	12.25	12.17	0.65
1300	12.25	12.17	0.65
1400	12.25	12.16	0.65
1500	12.25	12.16	0.74

Similar to Table 1, Table 2 shows values obtained from a test of voltage regulation at a test voltage of 5V when load of 100-1,500Ω is applied. As shown in the table, two distinct stable voltage regulation states and a drift are observed. At load of 900-1,000Ω a sudden upward surge in current drawn by the load occurred showing instability of 0.2% in regulation. Observably, with increase in applied load from 1,050Ω and above better voltage regulation was observed all at a test voltage of 5V.

The trend of this increased is plotted in Figure 4(a), while the voltage drop at around 5V is plotted in Figure 4(b).

Figure 3. Graph of plot showing percentage regulation against load

Table 2. Percentage regulation at 5V with varying resistive load
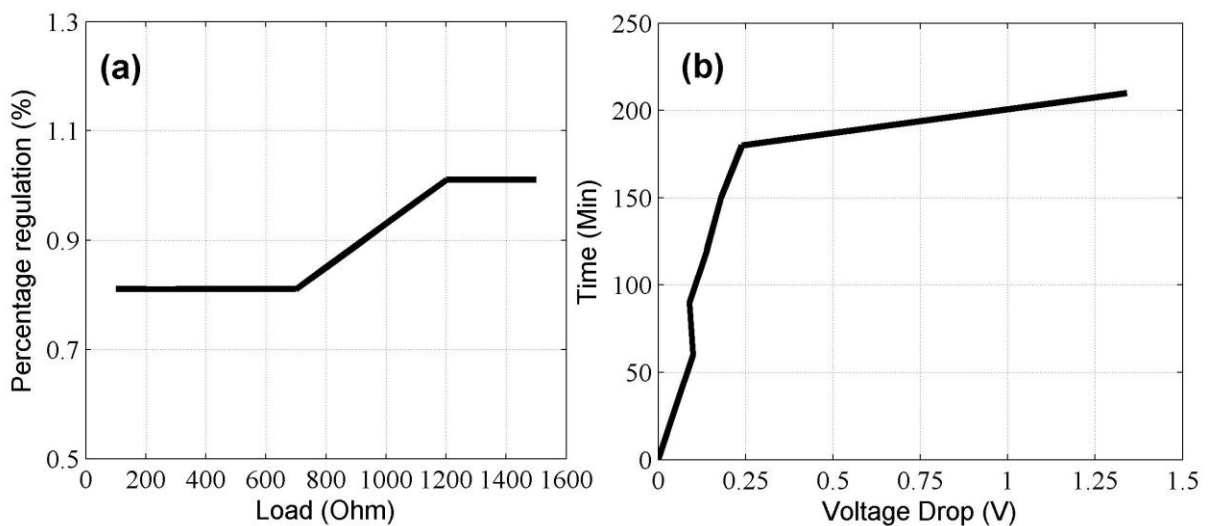
Load (Ω)	Positive voltage (V) V_{NL}	Positive voltage (V) V_{FL}	Regulation (%)
100	5.00	4.96	0.81
200	5.00	4.96	0.81
300	5.00	4.96	0.81
400	5.00	4.96	0.81
500	5.00	4.96	0.81
600	5.00	4.96	0.81
700	5.00	4.96	0.81
800	5.00	4.96	0.81
900	5.00	4.96	0.81
1000	5.00	4.95	1.01
1100	5.00	4.95	1.01
1200	5.00	4.95	1.01
1300	5.00	4.95	1.01
1400	5.00	4.95	1.01
1500	5.00	4.95	1.01

In order to see the voltage drop during the operation, we have tested the circuit at 12V with a 5W LED bulb as load as presented in Table 3. It was observed that at the fixed voltage of 12V the connected LED bulb remained bright providing illumination for up to 3 hours (180 minutes) with minimum voltage drop. Beyond 3 hours, the brightness of the bulb dropped as a result of the high voltage drop observed. The testing system is shown in Figure 5. From the table, increasing of time
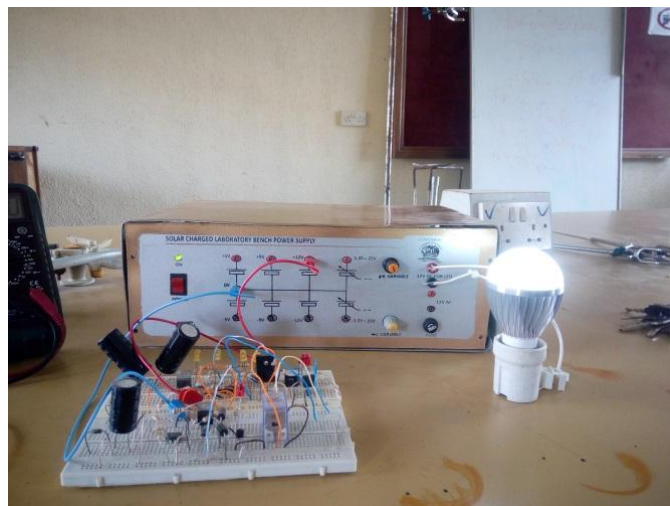
operation of the power supply will significantly increasing the voltage drop which is a possibly by dissipation energy.

Table 3. Time - Voltage drop at 12V with 5Watt LED bulb as load

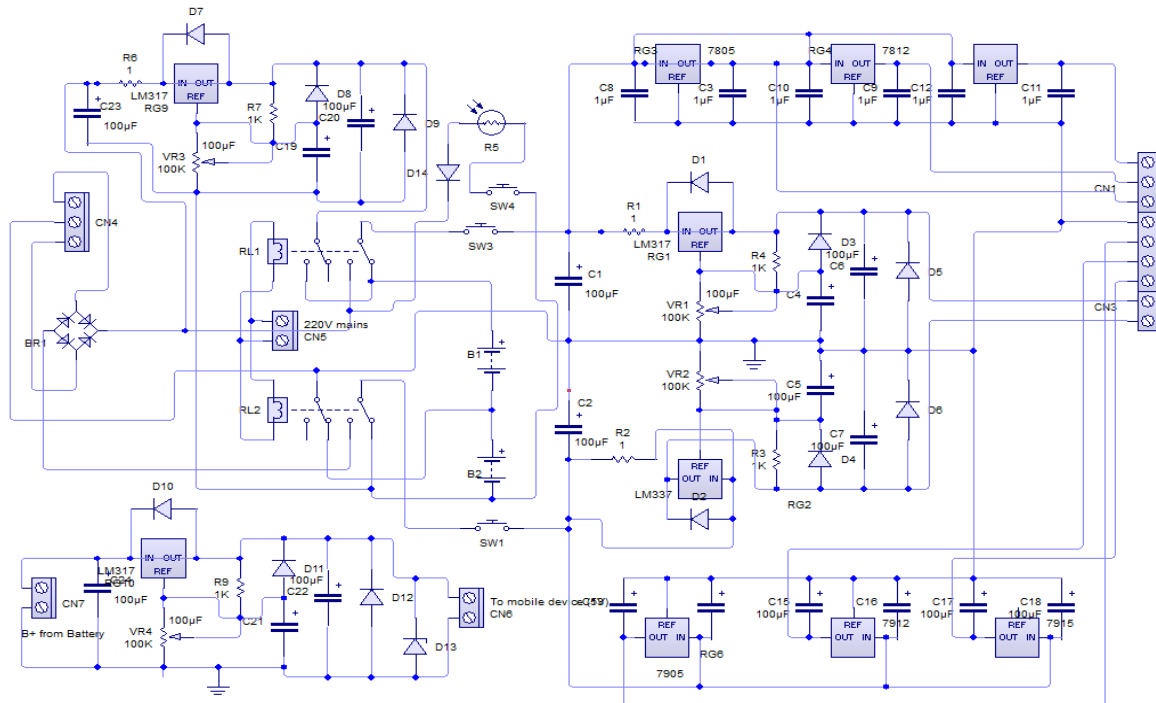| Time (min)	Voltage (V)	Voltage at time t (V)	Voltage drop (V)
0	12.00	12.00	0.00
30	12.00	11.95	0.05
60	12.00	11.90	0.10
90	12.00	11.91	0.09
120	12.00	11.86	0.14
150	12.00	11.82	0.18
180	12.00	11.76	0.24
210	12.00	10.66	1.34

Figure 4. (a) Graph of plot showing the percentage regulation against load and (b) Voltage drop at 12V with 5 Watt LED bulb as load

Figure 5. Picture of the power supply being tested in the laboratory to power a 7W LED bulb and a circuit on bread board

As can be seen from Figure 5, the device is not plugged into mains supply, yet from the energy stored in the power bank using a solar panel, it is being used to power a 7 Watt LED bulb and a circuit under test. This has eventually corrected the usual need to either stop or postpone an experiment in the laboratory due to an erratic power supply or total power outage from the mains. The observed result obtained from Figures 3 and 4, it shows that the power supply has better voltage regulation at a lower voltage as compared with the result obtained at a fairly increased voltage i.e. 12V. The power supply showed appreciable voltage regulation of over 80%. Figure 6 shows the complete circuit diagram for the development of a solar charged laboratory bench power supply.

Figure 6. Complete circuit diagram

6. Conclusion

This work has successfully presented a power supply that is functional, low cost and durable. The test carried out shows that the power supply can support basic experiments in electricity and electronic class hence ensuring that no practical class is suspended in the absence of supply from the mains.

Acknowledgement

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