



A Multifunction Automatic Smart Controller for Solar and Grid System for Household Utility

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ABSTRACT: Solar energy is a non-depleting, site dependent, non-polluting, and potential source of energy. However it is of unpredictable nature. It is of prime importance to develop a supervisory system which controls and monitors the energy production and also evaluates the consumption. This is necessary so as to maintain a balance between the production and consumption needs.

The Photovoltaic (PV) power systems convert sunlight directly into electricity. PV power system installed at a residence can generate electricity which can meet most or his total electricity requirement .Excess power generated during daytime can be used for future need i.e. at night time. Thus the house remains connected to the electrical utility all the times.

The proposed system is called a 'Multifunction Automatic Smart Controller for Solar and Grid System for Household Utility'. This consists of a smart controller based design for cost effective operation of solar-grid tied system. The proposed method is cheap, efficient, reliable and cost effective. The system has been tested for the 20 Watt solar panel with the battery backup storage and its effectiveness is observed. Hardware implementation of Incremental Conductance MPPT using Buck Converter is designed and explained.

KEYWORDS: Incremental Conductance, MPPT, Photovoltaic Module ,SEPI.

I. INTRODUCTION

Conventional energy sources based on coal, oil and natural gas have driven the economy for years and have facilitated the industrial revolution. But in turn they have left a damaging effect on the human health and environment. Furthermore with each passing day they are depleting at a very fast pace and scientists estimate the by the end of this century we may end up with these conventional energy reservoirs. Therefore, these traditional fossil fuel-based energy sources are facing increasing pressure on a host of environmental fronts, with perhaps the most serious challenge to face the future use of coal being the Kyoto Protocol greenhouse gas (GHG) reduction targets. Solar PV modules (Solar cells) are solid-state semiconductor devices with no moving parts that convert sunlight into direct-current electricity. The basic principle underlying the operation of PV modules dates back more than 150 years, but significant development really began following Bell Labs' invention of the silicon solar cell in 1954. The efficiency of solar cells depends on lots of factors and these factors vary from region to region. Today, Photovoltaic (PV) generation is becoming increasingly important as renewable source since it requires less maintenance , zero pollution , less maintenance and does not produces any .It is clear that PV modules have relatively low conversion efficiency; therefore, in a PV system the controlling Maximum Power Point Tracking (MPPT) for the solar array is essential. Solar panels generate power by using the photovoltaic effect: electrons are transferred between different energy bands in the atom by means of irradiation. The solar panel has a characteristic p-v characteristic where a global maximum is present. This means that for a different operating point of the solar panel, a different output power is obtained. Therefore, only for one specific operating point, the maximum power output is obtained from the solar panel. This point in the P-V characteristic is called the Maximum Power Point (MPP). This MPP changes when the irradiation and temperature changes or when the solar panel is partially shaded. At the maximum power point, the PV operates at its highest efficiency. Therefore, several methods have been developed for determining the MPPT. In addressing the poor

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efficiency of PV systems, some methods are proposed, among which is a new concept called “Maximum Power Point Tracking” (MPPT). All MPPT methods follow the same goal which is maximizing the PV array output power by tracking the maximum power on every operating condition. A switch-mode DC-DC converter is heart of MPPT hardware. A DC-DC converter therefore implemented to produce a constant voltage and deliver maximum power from solar panel to load. The output voltages of dc-dc converters are generally controlled by using a switching concept. IGBT's or MOSFET'S are used for this purpose. For output voltage regulation Pulse width modulation (PWM) is widely used.

II.SYSTEM MODULES

2.1 Maximum Power Point Tracking (MPPT) Methods

The Maximum Power Point Tracking (MPPT) Methods are usually implemented PV modules so as to increase the efficiency of PV modules. The MPPT methods are:

- (i) Perturb and Observe Method
- (ii) Constant Voltage Method
- (iii) Incremental Conductance Method

2.1.1 Perturb and Observe Method

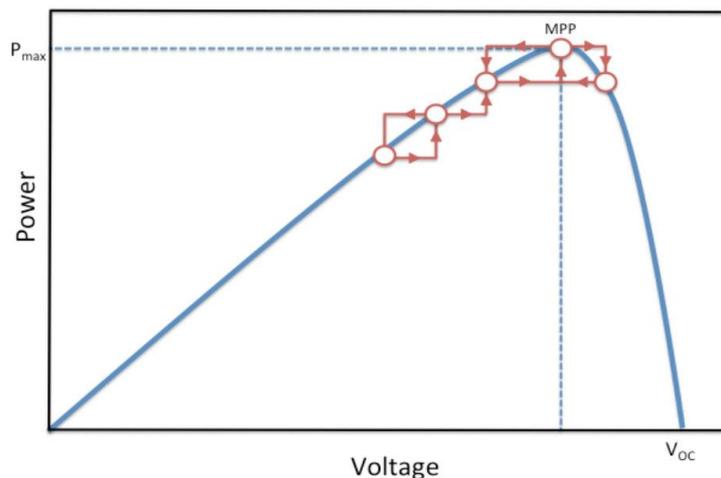


Figure 1 The Perturb and Observe Method for MPPT

This method of power point tracking follows the procedure of constantly checking the voltage (or current in some systems) and continuing to increase the voltage as long as the power continues to increase. After passing over the maximum power point the power will begin to decrease which the algorithm will interpret as having gone too far and will start decreasing the voltage to compensate. This process continues to iterate until the maximum power point has been reached. Figure 1 provides a graphical representation of this algorithm in operation. One of the disadvantages of the perturb and observe method is that based on the algorithm, the system will continue to oscillate around the maximum power point. This can lead to inefficiencies, especially in situations when the irradiance is low and the power-voltage curve begins to flatten out. When this occurs, the perturb and observe method can sometimes have difficulty determining when it has actually reached the maximum power point. In addition sometimes this algorithm will perform several iterations in the wrong direction if it is affected by rapidly changing conditions. However, the perturb and observe method is widely recognized as the most common method for maximum power point tracking because of its simple design.

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2.1.2 Constant Voltage Method

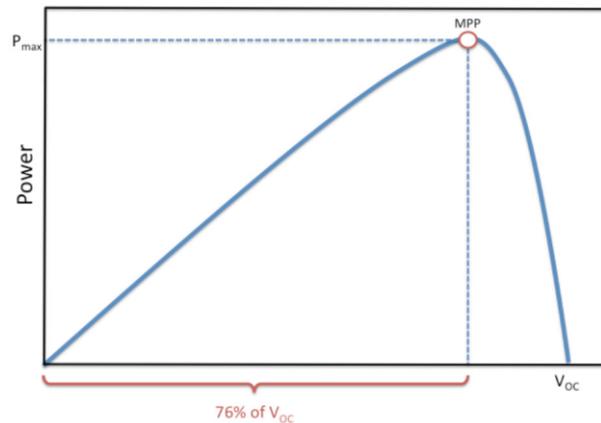


Figure 2 Constant Voltage Method for MPPT

The system will temporarily set the PV current to zero in order to determine the open circuit voltage. Once it has this value it can calculate, based on the specified ratio, what the operating voltage should be and the system can begin moving to that point. There is a specific amount of time, which can be programmed into the system, to wait before isolating the source and repeating the calculation. This method is inherently much less efficient than either the perturb and observe method or the incremental conductance algorithm. The primary advantage of this technique is that it requires much less computational time and is a much simpler algorithm than the previous methods.

2.1.3 Incremental Conductance Method

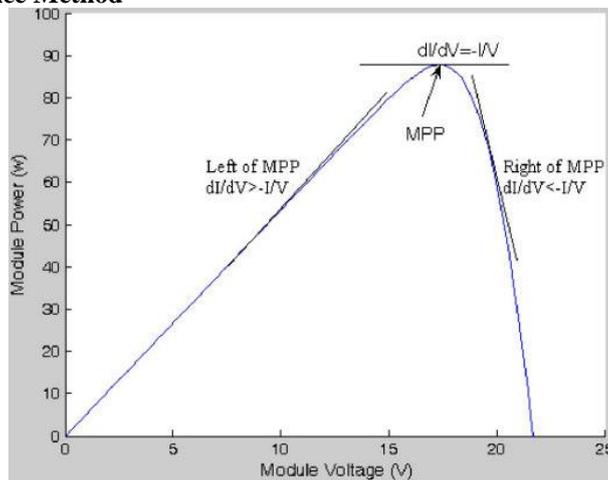


Figure3 Basic idea of the Incremental Conductance method on a P–V curve of a solar module

The Incremental Conduction method is the one which overrides over the aforementioned drawbacks. In this method, the array terminal voltage is always adjusted according to the MPP voltage. It is based on the incremental and instantaneous conductance of the PV module. Figure3 shows that the slope of the PV array power curve is zero at the MPP, increasing on the left of the MPP and decreasing on the right-hand side of the MPP. The basic equations of this method are as follows:



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$$\frac{dI}{dV} = \frac{-I}{V} \quad \text{at MPP}$$

$$\frac{dI}{dV} > \frac{-I}{V} \quad \text{Left of MPP}$$

$$\frac{dI}{dV} < \frac{-I}{V} \quad \text{Right of MPP}$$

where I and V are the PV array output current and voltage, respectively. The left-hand side of the equations represents the Incremental Conductance of the PV module, and the right-hand side represents the instantaneous conductance. It is obvious that when the ratio of change in the output conductance is equal to the negative output conductance, the solar array will operate at the MPP. In other words, by comparing the conductance at each sampling time, the MPPT will track the maximum power of the PV module. The accuracy of this method is proven in where it mentions that the Incremental Conductance method can track the true MPPs independent of PV array characteristics.

2.1.4. Incremental Conductance with Direct Control Method

Conventional MPPT systems have two independent control loops to control the MPPT. The first control loop contains the MPPT algorithm, and the second one is usually a proportional (P) or P–integral (PI) controller. A less obvious, but effective way of performing the Incremental Conductance technique is to use the instantaneous conductance and the incremental conductance to generate an error signal.

$$e = \frac{I}{V} + \frac{dI}{dV}$$

And this e goes to zero at MPP; however, it is not zero at most of the operating points. However, the MPPT system of standalone PV is a nonlinear control problem due to the nonlinearity nature of PV and unpredictable environmental conditions, and hence, PI controllers do not generally work well.

In this work, the Incremental Conductance method with direct control is selected. The PI control loop is eliminated, and the duty cycle is adjusted directly in the algorithm. The control loop is simplified, and the computational time for tuning controller gains is eliminated. The feasibility of the proposed system is investigated with a dc–dc converter configured as the MPPT. It was mentioned that the power extracted from PV modules with analog circuitry can only operate at the MPP in a predefined illumination level. Therefore, control action is done using a PIC16F877A which performs various control actions. It generates pulse width modulation (PWM) waveform to control the duty cycle of the converter switch according to the Incremental Conductance algorithm.

2.2 Photovoltaic (PV) Module

A solar cell is basically a p-n junction fabricated in a thin wafer of semiconductor. The electromagnetic radiation of solar energy can be directly converted to electricity through photovoltaic effect. Being exposed to the sunlight, photons with energy greater than the band-gap energy of the semiconductor creates some electron hole pairs proportional to the incident irradiation. The equivalent circuit of a PV cell is as shown in Figure 5.

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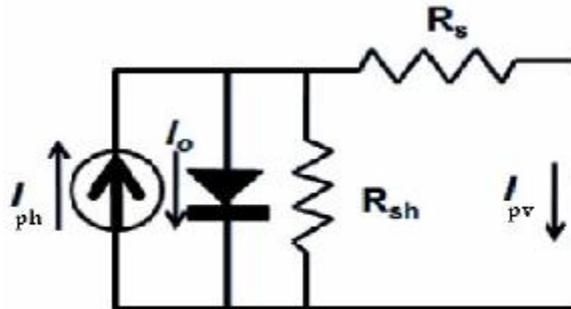


Figure 4 PV cell modelled as diode circuit

The current source I_{ph} represents the cell photocurrent. R_{sh} and R_s are the intrinsic shunt and series resistances of the cell, respectively. Usually the value of R_{sh} is very large and that of R_s is very small, hence they may be neglected to simplify the analysis. PV cells are grouped in larger units called PV modules which are further interconnected in a parallel-series configuration to form PV arrays. The photovoltaic panel can be modelled mathematically as given in equations (1) - (4). [1, 8]

Module photo-current:

$$I_{ph} = [I_{scr} + K_i(T - 298)] * \frac{\lambda}{1000} \quad \text{-----(1)}$$

Module reverse saturation current

$$I_{rr} = I_{scr} / \left[\exp \left(\frac{qV_{oc}}{N_s KAT} \right) - 1 \right] \quad \text{-----(2)}$$

The module saturation current I_{rs} varies with the cell temperature, which is given by

$$I_{rs} = I_{rr} \left[\frac{T}{T_r} \right]^3 \exp \left[\frac{q \cdot E_{go}}{B \cdot K} \left\{ \frac{1}{T_r} - \frac{1}{T} \right\} \right] \quad \text{-----(3)}$$

The output current of PV module is

$$I_{pv} = N_p * I_{ph} - N_p * I_{rs} \left[\exp \left(K_0 \frac{V}{N_s} \right) - 1 \right] \quad \text{-----(4)}$$

Where

- V_{pv} is output voltage of a PV module (V)
- I_{pv} is output current of a PV module (A)
- T_r is the reference temperature = 298 K
- T is the module operating temperature in Kelvin
- I_{ph} is the light generated current in a PV module (A)
- I_{rs} is the cell reverse saturation current (A)
- $A = B$ is an ideality factor = 1.6
- K is Boltzmann constant = 1.3805×10^{-23} J/K
- q is Electron charge = 1.6×10^{-19} C
- R_s is the series resistance of a PV module
- I_{scr} is the PV module short-circuit current
- K_i is the short-circuit current temperature co-efficient
- λ is the PV module illumination (W/m^2) = $1000 W/m^2$

Ego is the band gap for silicon = 1.1 eV
K0 is constant
Ns is the number of cells connected in series
Np is the number of cells connected in parallel

2.3 SEPI Converter

The **single-ended primary-inductor converter (SEPIC)** is a type of DC/DC converter allowing the electrical potential (voltage) at its output to be greater than, less than, or equal to that at its input. The output of the SEPIC is controlled by the duty cycle of the control transistor.

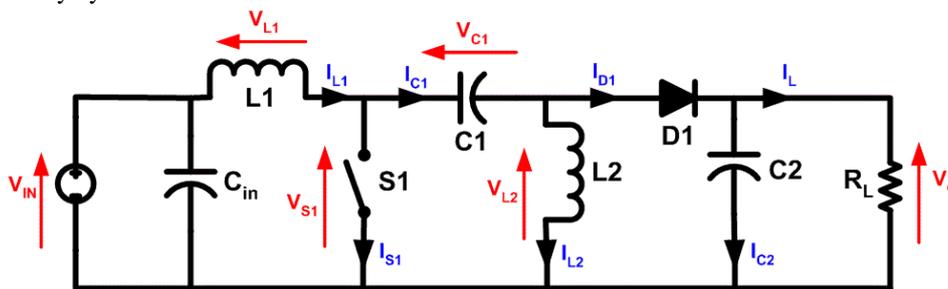


Figure 5 The schematic diagram for a basic SEPIC

A SEPIC is essentially a boost converter followed by a buck-boost converter, therefore it is similar to a traditional buck-boost converter, but has advantages of having non-inverted output (the output has the same voltage polarity as the input), using a series capacitor to couple energy from the input to the output (and thus can respond more gracefully to a short-circuit output), and being capable of true shutdown: when the switch is turned off, its output drops to 0 V, following a fairly hefty transient dump of charge.

The schematic diagram for a basic SEPIC is shown in Figure 6. As with other switched mode power supplies (specifically DC-to-DC converters), the SEPIC exchanges energy between the capacitors and inductors in order to convert from one voltage to another. The amount of energy exchanged is controlled by switch S1, which is typically a transistor such as a MOSFET. MOSFETs offer much higher input impedance and lower voltage drop than bipolar junction transistors (BJTs), and do not require biasing resistors as MOSFET switching is controlled by differences in voltage rather than a current, as with BJTs).

1) Continuous mode

A SEPIC is said to be in continuous-conduction mode ("continuous mode") if the current through the inductor L1 never falls to zero. During a SEPIC's steady-state operation, the average voltage across capacitor C1 (V_{C1}) is equal to the input voltage (V_{in}). Because capacitor C1 blocks direct current (DC), the average current through it (I_{C1}) is zero, making inductor L2 the only source of DC load current. Therefore, the average current through inductor L2 (I_{L2}) is the same as the average load current and hence independent of the input voltage.

Looking at average voltages, the following can be written:

$$V_{IN} = V_{L1} + V_{C1} + V_{L2} \text{-----}(5)$$

Because the average voltage of V_{C1} is equal to V_{IN} , $V_{L1} = -V_{L2}$. For this reason, the two inductors can be wound on the same core. Since the voltages are the same in magnitude, their effects of the mutual inductance will be zero, assuming the polarity of the windings is correct. Also, since the voltages are the same in magnitude, the ripple currents from the two inductors will be equal in magnitude.

The average currents can be summed as follows (average capacitor currents must be zero):

$$I_{D1} = I_{L1} - I_{L2} \text{-----}(6)$$

2) Discontinuous mode

A SEPIC is said to be in discontinuous-conduction mode or discontinuous mode if the current through the inductor L1 is allowed to fall to zero.

The voltage drop and switching time of diode D1 is critical to a SEPIC's reliability and efficiency. The diode's switching time needs to be extremely fast in order to not generate high voltage spikes across the inductors, which could cause damage to components. Fast conventional diodes or Schottky diodes may be used.

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The resistances in the inductors and the capacitors can also have large effects on the converter efficiency and ripple. Inductors with lower series resistance allow less energy to be dissipated as heat, resulting in greater efficiency (a larger portion of the input power being transferred to the load). Capacitors with low equivalent series resistance (ESR) should also be used for C1 and C2 to minimize ripple and prevent heat build-up, especially in C1 where the current is changing direction frequently.

III. SYSTEM ANALYSIS & DESCRIPTION

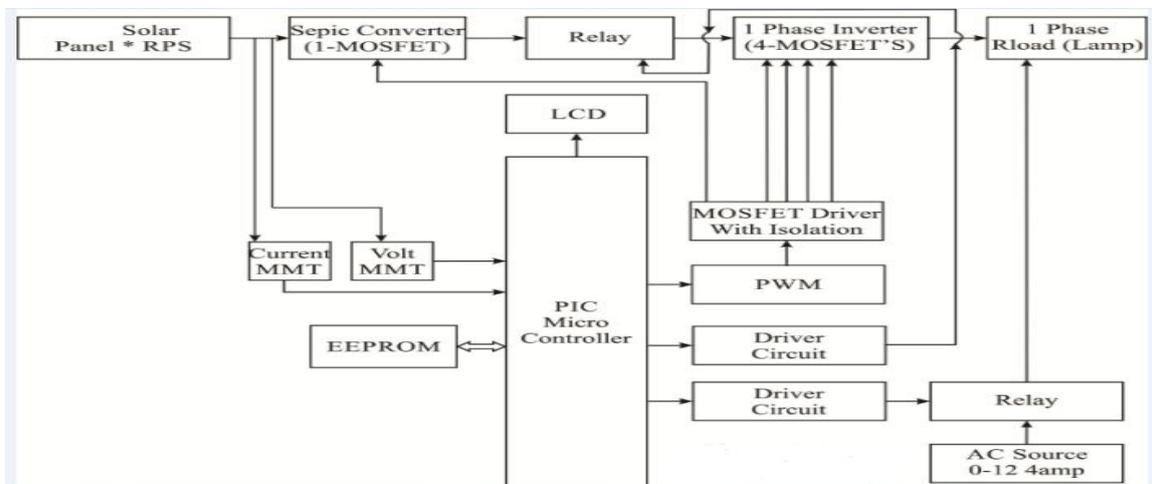


Figure 6 Block Diagram of the system

To track the Maximum power point, a Hardware section is required which consist of different parts. The figure 7 above shows the block diagram of the system. It consist of Solar Panel ,SEPIC Converter, Invertor , Microcontroller, Opto Coupler , Liquid Crystal Display , current and voltage measurement unit and driver circuits. The solar panel will harness the solar power which is stored in the battery. The microcontroller switches the supply between the mains and the battery through the relays. The SEPIC convertor maintains the battery voltage and also charges the batter. The microcontroller also provides the PWM pulses at the gate of the MOSFET

IV. EXPERIMENTAL SETUP



Figure 7 The Experimental Setup



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The solar panel supplies voltage to the buck boost (sepic convertor) .The buck boost convertor ensures that the voltage is maintained at 12 v .The buck boost convertor supplies the voltage to the battery .Initially the solar panel output is given to the battery. The output of the solar panel is DC hence this DC output will charge the battery as the battery can accept only DC input and provides DC output. The solar panel used in the circuit is of 12V and also the battery used is of 12V.Now this DC output from the battery is given to the inverter circuit which converts the DC signal to AC. The converted AC output is given to the relay which acts as an automatic switch. The output load is connected to the relay, so whenever the relay gets a ON signal from the microcontroller unit , it will turn ON the output load and whenever the input to the relay is OFF, it will turn OFF the output load.

When the battery level goes below a specific value then mains will drive the relay and the relay will then drive the load. Simultaneously the AC supply is converted to DC .The DC voltage will drive the opto coupler which will then trigger the SEPIC convertor and the battery gets charged.

The microcontroller is the heart of the circuit that would provide switching between the AC mains and the battery. Actually both the relays connected in the circuit do not receive the signal directly via the battery and the AC mains instead they are connected to the microcontroller through which they turned ON and OFF the load.

The microcontroller decides the switching:

1. It first checks whether both the battery and the AC mains are available are not. If both are available then it considers the AC mains thereby keeping the battery output for backup. In this period of time the microcontroller checks the battery voltage, if the battery voltage is low then the solar panel charges the battery to the maximum.
2. If the AC mains is not available then it considers the battery voltage which is fully charged.
3. To display the values of input voltage and current and output voltage and current we have connected a LCD to the microcontroller.

V. RESULT AND DISCUSSION

Though numerous rechargeable batteries exist, the most commonly used battery in solar systems is the lead-acid battery. This is mainly because of the price to power ratio is superior to all other types and due to the fact that this is a proven technology. The lead acid battery of 12V is charged using MPPT technique. Table 1 below shows the observations of variation of voltage, current of battery and solar panel with respect to time which has been taken in the third week of December 2015 from 9:00 am to 6:00 pm.

| Time | Input voltage (Volts) | Input Current (Ampere) | Power (Watts) |
|---------|---------------------------|------------------------------|-------------------|
| 9 a.m. | 13 | 0.02 | 0.26 |
| 10 a.m. | 14.2 | 0.022 | 0.31 |
| 11 a.m. | 15 | 0.024 | 0.36 |
| 12 noon | 15.5 | 0.028 | 0.43 |
| 01 p.m. | 16 | 0.029 | 0.46 |
| 02 p.m. | 17 | 0.030 | 0.51 |
| 03 p.m. | 17.5 | 0.031 | 0.54 |
| 04 p.m. | 15 | 0.024 | 0.36 |
| 05 p.m. | 12 | 0.015 | 0.18 |
| 06 p.m. | 06 | 0.001 | 0.006 |

Table 1 Observation of variation of Voltage , and current of the solar panel



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VI. CONCLUSION

Thus we have been able to design a multifunction automatic smart controller for solar and grid System to be used as household utility where MPPT was tracked effectively by using a SEPIC Converter. Controller algorithm for a smart controller based solar-grid hybrid system has been presented, specifically for effective utilization of power from the Solar PV. All techniques rely on the ability of effective co-operation of different units in the hybrid system and mainly the programming algorithm and interface used with smart controller. The described algorithm is demonstrated with practical observation from the lab. This method can be used as a cheap alternative to save energy even in a Grid tied system and it is expected that the consumer will be encouraged to use this form of energy in place of the grid. Effective use of such an alternative will ease out the burden on the existing grids and will also play a positive role in terms of its effect on the climatic conditions.

Future work may involve developing different Microcontroller based dedicated MPPT controller for solar PV module based on the different algorithm such as observe & perturbation, computational method etc. Future work may involve making the system remote controlled with usage of battery banks to improve the reliability of the system.

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