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DESIGN OF A SOLAR HYBRID ELECTRIC MINI TRACTOR

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ABSTRACT

A solar hybrid electric mini tractor is a vehicle which works on electrical power as well as fuel like petrol. The thought is to design and construct a solar hybrid electric mini tractor powered by battery as well as petrol. These vehicles are made dynamic in nature by making use of electrical power with motor from battery and IC engine fuel power. Now a days, Fuel Efficiency and minimum pollution or zero tailpipe emission in vehicles is a major research area. Solar Hybrid Electric vehicles are becoming popular because they are fuel economical by using renewable source and upgraded to provide power and speed upon need without any charging limitations. But the major setback in them is their long charging time. The implementation of solar hybrid electric technology on the mini tractor is done in a parallel hybrid configuration. It consumes less fuel and creates comparatively less pollution (0 tailpipe emission can also be possible) as compared to conventional vehicles. Hybrid electric vehicles consists of a rechargeable battery, to drive the electric motor and the power with an IC engine to increase fuel economy reduce harmful emissions from the exhaust not only that, there is a provision for recharging the battery using a generator. In solar hybrid electric mini tractor, the battery single provides power for driving at low speeds where the efficiency of IC engine is least. In high load conditions the electric power gives the extra energy to the engine by providing additional power. Thus, the solar hybrid electric mini tractor is the best alternative in areas with high traffic like urban metropolitan cities. This research, discusses all the electrical designing and implementation of this technology on the mini tractor.

Keywords: Hybrid Vehicle (HV), Electric Hybrid Vehicle (EHV), Solar Hybrid Electric Vehicle (SHEV), Solar Hybrid Electric Mini Tractor (SHEMT), Plug-In Hybrid Vehicle (PHV), Fuel Cell Hybrid Vehicle (FCHV), Parallel Hybrid Configuration (PHC).

I. INTRODUCTION

Historically, agricultural electric mini tractor systems, were developed and employed nearly a hundred years ago but vanished with the increasing availability of fossil fuels and the progress in the development of combustion engines. [1] Ferdinand Porsche developed the "Lohner Porsche" in 1901, But the hybrid electric vehicles did not become widely available until and unless the release of the Toyota Prius in Japan in 1997,[2] followed by the Honda Insight in 1999. Initially, the hybridization seemed unnecessary due to the low cost of gasoline or fossil fuel. Nilsson et al has published a patent in 1902 on electro gasoline vehicle in which he explains the series hybrid electric vehicle topology. A Plug in Parallel Hybrid Electric Vehicle has been developed with the idea of regenerative breaking. In 1979 a parallel hybrid car with electric and heat engine has been designed. For increasing the efficiency of ICE, a series hybrid system using AC machines has been developed in 1979. The first Hybrid Vehicle based on solar technology was made in 1990 in Germany. Few models of a zero-emission vehicle have been launched in 1990 by California Air Resource Board. Hydrogen fuel cell-based batteries hybrid cars [3] did not flourish because of high cost. Worldwide increases in the price of fossil fuel caused many automobile makers to release hybrids in the late 2000s; they are now perceived as a core segment of the automotive market of the future. Researchers are putting efforts to bring forward the improvement in Hybrid Vehicles. [4-7] Modern HEVs make use of efficiency improving technologies such as regenerative brakes which convert the vehicle's kinetic energy to electric energy, which is stored in a battery or supercapacitor. now HEV uses an internal combustion engine to turn an electrical generator, which either recharges the vehicle's batteries or directly powers its electric drive motors for heavy load conditions this combination is known as a motor–generator.[8] Many HEVs reduce idle emissions by shutting down the engine at idle and restarting it when needed; this is known as a start-stop system. The presence of the electric powertrain is intended to achieve either better performance. The most common form of HEV is the hybrid electric car, scooter although hybrid electric trucks (pickups and tractors) and buses [9-12] also exist. Solar Hybrid Electric Vehicle [SHEV] is a combination of internal combustion engine along with the electric propulsion system. The electric power train assists in achieving a better performance and fuel economy. Due to heigh oil prices, global interest has increased towards SHEV. People are facing pollution and SHEV has the ability to decrease the GHG emission [13] as well as other pollution caused by vehicles. Today, due to the perspective of locally available renewable electric energy there is a completely different scenario for rural areas, which is the cause of the efforts to resume the development of solar electric tractors for agriculture. The main application of an agricultural solar tractor is to power implements by pulling plows, seeders, harvesters [14-16] etc. The worldwide oil demand is high while its supply is becoming low. According to a report the utilization of crude oil is about 15 million barrels in a country out of which 69% has been used in transportation sector and fuel consumption has an uprising trend and is expected to continue to grow. The reported fuel economy in SHEV projects is about 20% to 40% respectively [17-21]. Therefore, these types of vehicles can be considered as the solution of the energy shortage. Additionally, the design of an SHEMT has to consider the specific properties of the electric motor and its controls in conjunction with the tractor's onboard energy source. Compared to a combustion engine driven tractor, this leads to a different configuration of the drive train and the associated energy supply system. This research paper has been structured as follows. Proposed Methodology is described in section II. Suitable SHEV Configuration and electrical and mechanical design has been discussed in section III and IV. Complete technical design and implemented hardware design is described in V and VI while the results and conclusion have been introduced in section VII and VIII respectively.

II. PROPOSED METHODOLOGY

Solar Hybrid Electric Mini Tractor (SHEMT) is a Mini Tractor, which is based on Solar technology. To make an economical and powerful hybrid Mini Tractor, it is desired for it to be lighter, less complex, heavy load capacity, produces less or no pollution inside the city.

A. Selection of Hybrid Vehicle Type:

TABLE 1. COMPARISON BETWEEN MOST FAVORABLE HV TYPES

Characteristics	SHEV	FCHV	PHV	BEV
Simpler Configuration	Complex	Complex	Moderate	Moderate
Reliable	Yes	No	Yes	Yes
Light Weight	Medium Weight	Medium Weight	Large Volume of Cylinder or Bladder	Medium Weight
Minimum Maintenance	Yes, Only Battery Replacement	Medium Maintenance	Medium Maintenance	Yes, Only Battery Replacement
Quick Response	Yes	No	Yes, But Peak Power Is Compromised	Yes, But Peak Power Is Compromised
Efficient	Up To 50%	Up To 69%	50%	Up To 50%
Less Pollutant	Zero Emission Possible	Zero Emission Possible	Zero Emission Not Possible	Never Produce Tailpipe Emission
User Friendly	Yes	Somewhat	Yes	Yes

This comparison shows that SHEV type is the best possible solution to be utilized in a SHEMT.

B. Selection of suitable SHEV configuration:

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TABLE 2. COMPARISON OF MOST FAVORABLE SHEV CONFIGURATION

Characteristics	Series hybrid configuration	Parallel hybrid configuration	Power-split hybrid configuration
Simpler Configuration	Less complex Two electrical machines	Less complex one electrical machine	very complex power electronics Two electrical machines
Independent Operation	Only one source propels the vehicle	Both sources can propel independently	Both sources can propel and assist each other
Fuel Efficient	Start/stop functionality	Start/stop feature Independent operation	Start/stop feature Independent operation
Speed/Power Impact	Limits, speed and power	Not compromised due to independent source operation	Not compromised
Capital Cost	Less	Moderate	High

From the above table it is clear that the parallel hybrid configuration, is best to use in SHEMT. PHC is less complex as it is having only one electrical machine.

III. ELECTRICAL COMPONENTS CALCULATION

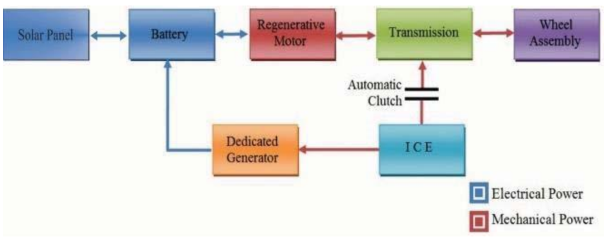

FIG 1. PARALLEL HYBRID CONFIGURATION WITH MODIFICATION

The block diagram of Parallel Hybrid Configuration is shown in figure 1. The blue arrows show the flow of electrical energy and the red arrows show the flow of mechanical energy between the component blocks. The bidirectional arrows show that the components must be connected in such a way that a bidirectional flow of electrical and mechanical energy is possible. The arrow from the ICE block shows a unidirectional energy flow because ICE is connected to the transmission through a clutch, which prevents power from going back to the ICE and thus engine remains isolated in case of a reverse mechanical power flow. On the other hand, the motor or generator block is connected without a clutch which enables it to accept reverse flow of mechanical power. Upon reverse flow of mechanical power towards the motor/generator (MG) block, either motor starts to act as a generator or a separately coupled high efficiency generator starts rotating and produces electric power to charge the battery. Improvements will be made to the PHC design in order to achieve most beneficial operation for the base design. The Improvements includes using a separate generator, plug-in charging support, regenerative ability and drive train bypassing.

Basic requirements:

TABLE 3. APPROXIMATELY SPECIFIED ACHIEVABLE HEMT PARAMETERS

Specification name	Specified achievable values (approx.)
HEMT's weight	350-420 Kg
Maximum loading weight	80 Kg (one passenger)
Top speed	60Km/h

Acceleration	0-60 Km/h in ≤ 150 seconds
Total power	4 HP or 5KW
Effective range	70Km/L to 100Km/L

These table include SHEMT's weight, total weight carrying ability, acceleration, top speed, power, and effective distance coverage range. All required specification for the SHEMT is listed in the table III.

Electric Motor Specification

The known parameters are as follows

1. Max load = weight of HEMT + weight of a passenger = 420Kg + 80Kg = 500Kg
2. Top speed on electrical powertrain = 40Km/h
3. Acceptable acceleration time ≤ 150 seconds
4. Wheel diameter = 21.5 inches
5. Initial velocity $V_i = 0$
6. Time taken to achieve top speed = t = 90s
7. Terminal voltage = v = 48 V DC

The assumptions made as follows

1. Motor is assumed to power the wheel from the centre of axis, axel diameter and gears are neglected.
2. Disc wheel is assumed
3. Maximum mass of the mini tractor is subjected to the rear wheel.

In order to specify a motor, the parameters to be computed are

a) Power of electric motor = P_{motor} and motor's current drain = I_{motor}
b) Holding torque of the motor = $Ꞇ_{motor}$

Calculation

a) Max. load on the motor = max. weight it has to move

So, maximum load = W = 500Kg

We know that

1Km/h = 0.621371 $M_p h$

Required top speed by the electrical powertrain = S = 40Km/h = 24.85 $M_p h$

We know that

F = μ × R -------------------------------(1)

Coefficient of rubber to concrete friction = μ = 0.015

Converting weight into lb/ft to compute R

R = W × 2.2--------------------------------(2)

R = 1100 lb/ft

Computing the force 'F' at wheels

F = 16.5 lb/ft

Computing the power in horsepower (P_{hp})

$P_{hp} = \frac{F \times S \times (22/15)}{550} = 1.09\ HP$--------------------(3)

But the power of electric motor required in watts,

We know that

1HP = 745.7 watt

$P_{motor} = 813\ watts$

Motor current drain can be computed by

P = VI-------------------------------(4)

I = 16.93 Amps

$I_{motor} = 16.93$ Amps

b) Computing the holding torque of the motor = Ꞇ

Ꞇ = I × a--------------------------(5)

Where I, is the moment of inertia and 'a' is the angular acceleration

I = $\frac{1}{2}Mr^2$ ----------------------------(6)

Where ‘M’ is the mass (of wheel along with rest of the vehicle) in Kg, ‘r’ is the radius of the wheel itself.

Diameter of Wheel = D =21.5” = 0.546 m

Radius of the wheel = r =D/2 = 0.546/2 = 0.27 m

I = $\frac{1}{2}$ (500) (0.27^2) = 18.22 Kg. m^2

After computing I, now computing angular acceleration ‘a’ which is the other unknown in equation (5).

a = $\frac{\Delta\omega}{\Delta_t} = \frac{\omega_f - \omega_i}{\Delta_t}$---------------------------------(7)

Where ω_i is the initial angular velocity of the wheel and ω_f is the final angular velocity of the wheel, As the acceleration of the motorbike is to be computed from rest position to its top speed

So, Taking initial velocity = $V_i = 0Km/h = 0rad/sec$

And final velocity (top speed) = V_f = 40Km/h = 11.11 m/s

Converting linear velocity to angular velocity

V = r × ω-------------------------(8)

$$V_{f\ rpm} = \frac{11.11}{0.27 \times 0.10472} = 393\ rev/min$$

$$V_{f\ rev/s} = 6.55\ rev/s$$

Converting from rpm to radian/second

$$\omega_f = \frac{6.55\ rev}{1\ s} \times 2\Pi\ rad = 41.15\ rad/s$$

a = $\frac{41.15-0}{90s}\ rad/s^2$

from equation (5)

$C_{motor} = 8.19N.m$

Selection of battery and battery bank specification

The known parameters are as follows

1. Motor Power = P = 813 watts, Voltage Level = V = 48VDC, Maximum Peak Current Drain from the battery = $I_{peak} = 30A$ (Highest possible value taken into account so that components remain in safe ranges)
2. Motor’s maximum current draw = I_{motor} = 16.93 Amps

Operation time = 1.25 hours

The assumptions made is that Minimum current drawn by motor $I_{min} = 5.5A$ (approx. > 1/3 of total motor power). The parameters to be computed are required capacity of battery, discharging time and rate of discharge.

Calculation

Capacity of the battery

C = AT---------------------(9)

Where ’A’ is the amperes drawn from the battery, ‘C’ is the capacity of the battery and ‘T’ is the operation time.

Maximum capacity of the battery required ‘C_{max}’

$C_{max} = 16.93A \times 1.25\ hours = 21.16Ah$

Approx. minimum capacity of the battery required ‘C_{min}’

$C_{min} = 5.5A \times 1.25hours = 6.875Ah$

Average capacity of the battery,

$C_{avg} = (C_{min} + C_{max})/2 = 14.01$Ah---(10)

Average current drawn by the motor from battery = $I_{avg} = \frac{16.93+5.5}{2} = 11.215\ A$

Now taking cycle life in to consideration, so that the battery doesn’t gets empty. It is recommended to leave 20% of the battery charged in order to enhance the cycle life of the battery. Leaving 20% in reserve, the remaining useful capacity is 80%. Adding usable capacity to the average ampere-hour capacity gives 'C`' which is the acceptable capacity of the battery including 20% reserve margin.

C` = C_{avg}/0.8 = 14.01/0.8 = 17.51Ah--------------------(11)

Computing discharging time

$T_{discharging} = \frac{battery\ power(\ watt.hour)}{load\ power\ (watt)} = 17.51 \times \frac{48}{11.215 \times 48} = \ 1.56\ \ hours$ ----(12)

Rate of discharge = 1/1.56 of C`

Discharge rate = 0.64 of C`

Now computing the capacity of battery required by compensating the calculated discharge rate.

C = C`/rate of discharge = 17.51/0.64 = 27.35 Ah---------------(13)

It is the required actual capacity of the battery. Both charging time $T_{charging}$ and charging rate are dependent on the charging equipment and battery's maximum Charging current specified by the manufacturer. These parameters will be computed with generator parameters.

Solar panel specification

Total panel = 4

Each panel = 10 watt

Model =

$P_{max} = 10\ watt$

$I_{mp} = 0.29A$

$V_{oc} = 21.6\ V$

$I_{sc} = 0.3A$

Max system volt = 1000V DC

Total Calculation for 4 panel

Total = 4 × 10 = 40 watt

$V_{mp} = 17.28\ \times 4 = 69.12\ Volt$

$I_{mp} = 0.29\ \times 4 = 1.16A$

$V_{oc} = 21.6\ \times 4 = 86.4\ Volt$

$I_{sc} = 0.3\ \times 4 = 1.2\ A$

Generator specification

An alternator generator needs to be connected to a prime mover whose speed is reasonably constant (to ensure constant frequency of the generated voltage) for various loads.

The known parameters are as follows

Battery capacity = C = 27.35Ah

1. Battery charging voltage per cell = 2.275 Volts (by data sheet)
2. Number of cells in the battery = 12 (by data sheet)

Number of batteries in the battery pack = 4, max. charging current = 3.6A

Assumptions

Efficiency of generator = 75%

the parameters to be calculated are as follows

Required Output Voltage of the Generator = V_{out}

Required Output Current of the Generator = I_{out}

Electrical power of the generator = P_{out}

Total mechanical power input = P_{mech}

Applied torque input = $C_{applied}$

Charging time of the Battery = $T_{charging}$

Charging rate of the battery

Calculation

This generator is for battery charging only, which means, electrical load will include the battery only. From the data sheet, it is known that

maximum charging voltage of battery is 2.275 Volts/Cell. Number of cells in the battery is 12, so the required output voltage of the generator is given as, Required Output Voltage = V_{out}=Max. Charging Voltage required by the Battery.

Max. Charging Voltage = charging voltage of each cell × number of cells.

Required Output Voltage = V_{out}= (2.275V × 12) = 27.3V = 24V(approx.)

Required current by the generator totally depends upon the max. Charging current of the battery specified by the battery manufacturer. In parallel charging of batteries current is divided so, max. Charging current for a 12V 12ah battery given in the data sheet is 3.6A. Using 4 such batteries in order to make 48 volts. So, Required Output Current of the Generator = I_{out} =3.6 × (4 batteries in parallel) = 14.4 A

Electrical power of the generator = P_{out} = 24V × 14.4 A = 345.6 watt

In ideal generator, $P_{out} = P_{in} = 345.6W = 0.463hp$ (converting in horse power)

For generator having 75% efficiency, the power loss will be 25% so, horse power loss = $P_{loss} = 0.463 \times 0.25 = 0.115\ hp$

Total power drawn by the generator, $P_{mech} = generator\ power + power\ loss = 0.463 + 0.115 = 0.578\ hp = 431.01\ Watt$

Calculating the required applied torque (at engine's idle speed 1500 rpm). Converting engine idle speed (1500rpm) to radians/second.

We know that,

1 rpm = 0.10472 rad/s

$$C_{applied} = \frac{P_{mech}}{\omega_m} = \frac{431.01}{157.07} = 2.744\ N.m$$

Now computing charging time for a 12Ah battery

$$T_{charging} = \frac{battery\ capacity}{charging\ current} = \frac{27.35\text{Ah}}{3.6\text{A}} = 7.5 \text{ hours}$$

Charging rate of the battery = 1/ $T_{charging} = \frac{1}{7.5\ hours} C = 0.133\ C$

Design of Buck Converter With MPPT

For recharging the battery with solar power, there is a usage of buck converter or DC-DC converter with maximum power point tracker in cooperated. A buck converter is used with a battery connected at the output terminal. The battery charging current is decided by the MPPT.

Known Parameters are as follows

1. Solar rated power = 210 Watt
2. Input voltage = 28-36 V
3. Output voltage = 12V
4. Switching frequency = 5Khz
5. Current ripple = 10%
6. Voltage ripple = 1%

Calculation

Output current = 210/12 = 17.5 A

Ripple = 10% of 17.5A = 1.75A

Voltage = 1% of 12V = 0.12V

Inductance, L =12(28 ×12) / 5000 × 1.75 ×28 = 0.783mH

Capacitance, C = 1.75 / 8 × 5000 ×0.12 = 364 µF

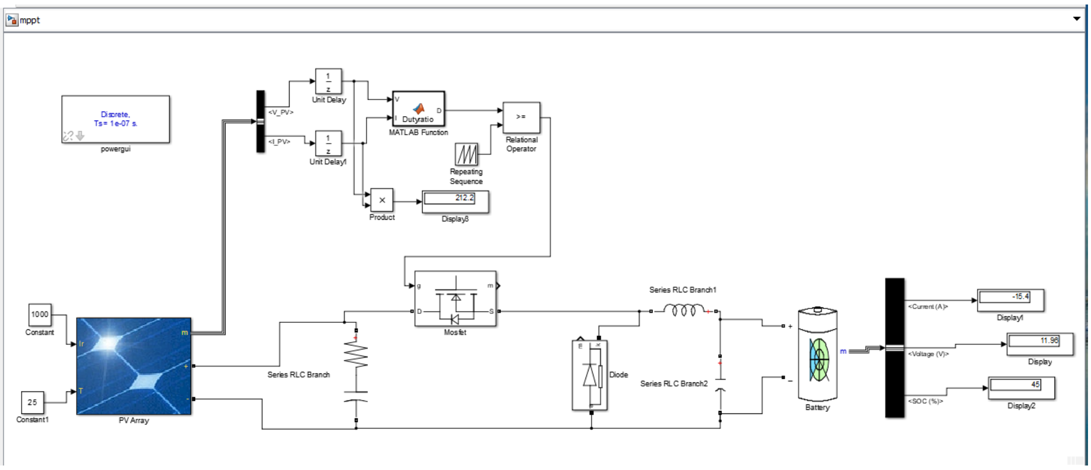

FIG 2. THE MATLAB DESIGN OF BUCK CONVERTER WITH MPPT

The design of buck converter is shown in FIG.II, the MATLAB design is about to charging of battery using solar PV array with the help of DC-DC converter with MPPT and it is showing the battery charging current, voltage and power delivered by the solar array.

IV. COMPLETE TECHNICAL DESIGN

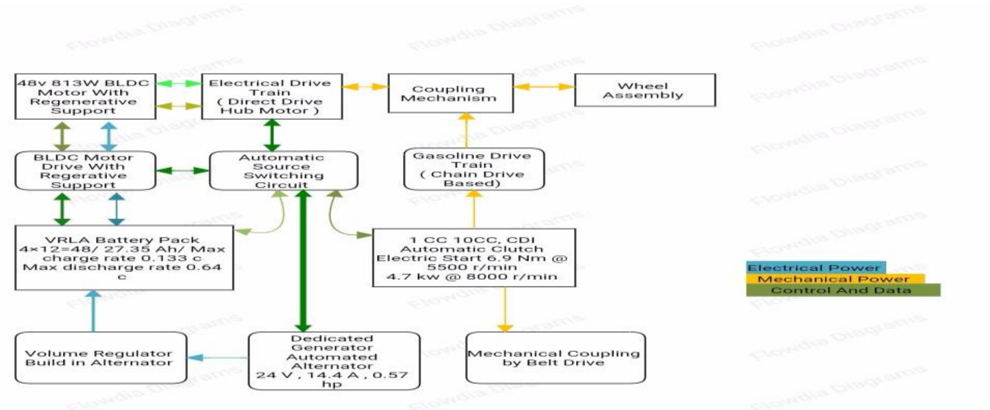

FIG 3. THE COMPLETE TECHNICAL DESIGN OF SHEMT

The final technical design of the SHEMT is shown in figure II. This technical design along with its theoretical values will serve as a base for obtaining hardware and its connections and couplings. The design shows that electric motor and ICE both are coupled to wheel assembly by a coupling mechanism. Electric Motor is to be connected to wheels by a direct drive mechanism such as a Hub motor. ICE powers the generator by a belt drive and the gasoline drivetrain with a chain drive mechanism. The generator (automobile alternator) charges the VRLA battery by converting ICE's mechanical power to electrical, and controls the battery charging with a built-in charge controller (Voltage Regulator). VRLA battery supplies power to the BLDC motor by a BLDC motor drive circuitry and whole electrical system of the SHEM. Automatic source switching circuit (ASSC) monitors the BLDC motor, Its controller the electric drive, Battery status, Generator status, and ICE's status.

V. RESULT

TABLE 4. comparison between conventional tractor and SHEMT

Duration	Conventional tractor	SHEMT
Fuel consumption per day.	Minimum of Rs. 200	Let's take it of RS. 100 for the sake of conventional tractor. Normally carrying light load, SHEMT does not use fuel at all
Fuel consumption for 1 year span.	200 × 365 days = Rs 73000	100 ×365 = Rs, 36500

This shows a huge saving of Rs 36500. Now to handle the argument on battery replacement, let's add cost of replacement of four VRLA batteries as well. The cost of 4 lead acid batteries used in this SHEMT prototype was about Rs.7200. Adding this cost for 1years, it becomes, 36500 + 7200 = Rs. 43,700. Normally VRLA battery need to change in two years. Still less than the conventional tractor.

VI. ADVANTAGES OF SHEMT

A. Cheaper than fossil fuels solar energy or renewable energy is actually much less expensive than fossil fuel but, the installation of solar or renewable energy will cost you more. We all know that solar energy compromises the electric bill charge. Most of peoples are unaware of just how, cost efficient renewable energy can be. Also, solar or renewable energy frees the farmers from the cost of or the hazard in rural area when electricity is all consumed at once.

B. Solution for drought-related problems Solar energy is much more efficient to adopt during this relentless drought because it takes minimum water quantity. For many, agriculture farm has grown uncommon and with limited water resources. Floating solar panels are acts as an alternative option to free up extra space on land which can be put to an alternative use in agriculture.

C. Solar energy is currently on the rise It's no doubt that the use of renewable solar energy has been growing exponentially in the last decade. For people, this means that the cost to install solar energy is likely to decrease. According to the Solar Energy Industries Association (SEIA), has grown 60% in the last decade [22-23]. The cost, however, has dropped over 70%. With the growing popularity of renewable energy, costs are predicted to continue declining. The advantages of solar energy will be seen through price reductions, new solar grid implementation in upcoming years.

D. Becoming more advanced solar panels have developed efficiently from its neutral state. Now, many of the solar panels do not using the glass substrate that the traditional models held. They are still attachable to roofs and walls. Also, panels tend to be much more environmentally friendly now [24]. That is due to less energy and less space being needed for its manufacturing process. The convenience of installing the solar panel is one of the major advantages of solar energy. battery storage has been growingly popular for the use of solar and renewable energy. Now a days Energy storage is essential for areas that are prone to natural disasters.

E. Most effective way to stop global warming Global warming has been a trend topic for everyone's. Utilizing renewable energy is one of the most effective methods of reducing a carbon particle. Solar panels produce renewable energy Not only that, but solar farms are able to help large amounts of clean energy, and this excess power being distributed onto main grids.

VII. CONCLUSION

For agricultural applications in rural areas without (or with) access to the grid, the solar hybrid electric mini tractor system provides the option to utilize locally generated renewable energy. The purpose of this research was to design a mini tractor using SHEV technology for a better fuel economy at as less cost as possible. It includes eliminating battery EVs limitations regarding distance range, operation time, charging time, heavy load, speed and power. Introducing a low cost and approachable SHEV solution to the consumer. Providing speed, economy and power simultaneously. Reviving and improving the market image of EVs, and SHEVs. Reducing pollution, tailpipe emission and increase awareness among people regarding its control. Introducing a mode of transportation with decreased environmental impact. Improving the project's level from prototype to a user-friendly product, with this change of technology significant benefits will be expected for the environment in addition to economic opportunities for the local population.

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