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Experimental evaluation of mobile multipurpose solar hybrid refrigeration system

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Abstract

The demand for small solar hybrid refrigerated vehicles has grown continuously throughout the world in the past few years for intercity perishable foodstuff transportation. These Small refrigerated electric trucks playing an important role in perishable foodstuff distribution from farm level to customer home. These battery operated trucks have potential regarding lower life cycle GHG emission and total lifetime costs. These hybrid trucks are a better alternative as compared to conventional diesel operated trucks. In this paper, we used the eco-friendly dual mode of power sources such as solar and grid energy for battery operated hybrid trucks. GPS system was installed in a hybrid truck for speed and route optimization. This hybrid truck was operated on 48V DC and its cooling unit was operated on 12V DC. This hybrid truck used four solar panels 150 W each in series and produced 2.5 to 4 KW power per day. These panels produced power (48V DC) was stored in four batteries which were connected in series. The experiment was performed on a clear sunny day in October month in NIT Jalandhar (Punjab) location in India. The main objective of this research paper was to check the energy consumption and hybrid system performance analysis. This article resolves the perishable foodstuff transportation problem in cold chain and has great significance in intercity as well as ruler areas application.

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Keywords: Refrigerated transport demand; intercity food truck; alternative modes of transportation; solar hybrid electric vehicle; supply chain

1. Introduction

India produced an enormous amount of fruits (90.2 million metric tonnes) and vegetables (169.1 million metric tonnes) during the year 2015-16. Due to higher post-harvest losses (20-30%) of perishable produce in our country, the per capita availability of fruits and vegetables is quite low. Perishable nature of the product requires a cold chain

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Nomenclature

EVs	Electric vehicles
GHG	Greenhouse gases
SMRS	Solar operates the mobile refrigerating system
VCR	Vapour compression refrigeration system
GDP	Gross domestic products
TRUs	Trucks
$PM_{2.5}$	Ambient particulate matter pollution
GWP	Global warming potentials
FAI	Food agency in India

transportation arrangement because after harvest these products do not supply immediately to the customer. Therefore these products quality deteriorates with supply time increase when it reaches the consumer. Maximum perishable nature of the product requires a cooling temperature between 0°C and 15°C for safe storage and transient purposes. The farmers want to sell their produce immediately after harvest at any price due to the absence of cold chain facilities, especially in ruler areas. If a farmer uses of cold chain facility can substantially improve storage quality and reduce wastage. An energy expense in cold storage in India is higher near around 28–30 percent of total expenses in the cold chain. Indian retail sector requires sustainable growing domestic and exporting demand (CSR, 2015). Frequently cuts in electricity are a very common problem in ruler areas of our country during peak summer. All these problems can be solved easily if we use solar power for operating small cold storage system in rural areas. Availability of solar energy in India is 4.6–6.6 kWh/m^2/day. Thus solar energy use in the refrigeration system is the best solution for ruler cold storage (MNRE, 2016). Today IC engine based trucks use for perishable products transportation in the cold food chain. These trucks have larger amounts of tailpipe emissions and give lower fuel economy. Availability of refrigerated vehicle in India is less and it does not fulfill the cold chain transportation demand. On the other side due to the fast growth of population in India foodstuff transportation demands continuously rise. These refrigerated trucks do not fit for smart city model because its size is too larger and its refrigerating unit demands excess fuel (20%) consumption. Trucks and refrigerated vehicles are mainly contribution to pollution generation especially in urban areas in road transportation. These refrigerated trucks emit twenty-nine times more particulate matter (PM) and six times more NO_x as compare to the normal truck engine. These refrigerated vehicles are not suitable for intercity foodstuff application because it does not provide door to door service to customers (WHO, 2018). Cold chain sector depends on two leading elements first is cold storage and second is refrigerated transportation. Around thirty-five thousand, the refrigerated vehicle uses in Indian cold chain transportation. More than eighty percent of these refrigerated vehicles are using for milk and pharmaceutical products transportation. Only eight thousand to ten thousand refrigerated vehicles are currently using for other perishable products transportation. Current Indian cold chain meets the need of around 52,826 to 62,000 new refrigerated vehicles (NABARD, 2017). India has the third position in Asian countries with global hunger index 31.4 and has finds100 rank out of 119 countries of worlds in 2017. India sufferers Rs. 92,473 cores of agricultural products loss annually in which perishable products losses are 50,473 cores. If India reducing food losses 30% to 15% then India able to provides 18.3 million tons of fresh foods each year for his hunger population its value is $3.9 billion. Therefore in such a dire situation, India requires to more focus on refrigerated vehicles for better development of cold chain. Indian cold chain refrigerated vehicles are completing his payback period between 2.5 to 4 year (GCC, 2018). The complication allied with conventional cold chain transport systems can be improved by the development of solar-powered electric refrigerated vehicles, which are gaining popularity in transforming cold chain transportation sector.

All the above problems will solve automatically if we start to use solar hybrid refrigerated vehicles (mini trucks) for Indian urban area. These developed vehicles have the ability to transport 50 to 350 kg commodity for 75 to 86 km intercity distance with a minimum cost of transportation at -16 to 35ºC temperature range. These solar hybrid refrigerated vehicles provide pollution free working. This paper focuses on performance analysis of solar hybrid refrigerated vehicles including energy consumption.

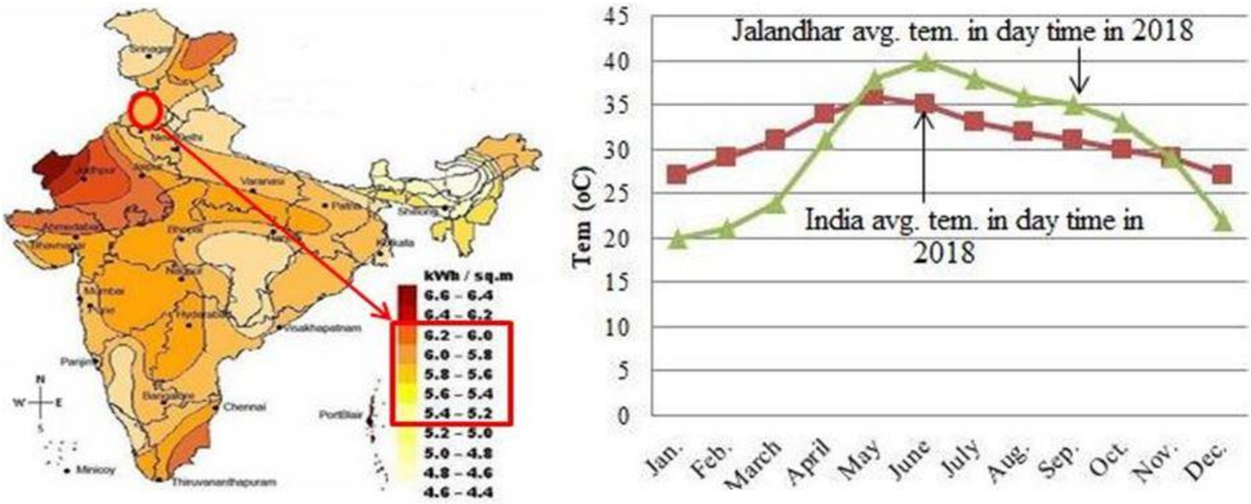

Fig. 1. Solar energy resource in India and temperature variation profile India *Vs.* Jalandhar city (Nasa India & MNRE India, 2018).

2. India energy resource and experimental day environmental condition

Solar power is the abundant source of energy especially in developing countries such as India. India situated on the solar belt near to the north equator and receives great penitential of solar energy annually with rate 1600-2200 kWh/m^2. Economic progress with environmental sustainability requires today for each developing countries (Dwivedi et al., 2016). According to geographical location, it lies in Asia zone latitude (21.7679° N) and longitude (78.8718° E). India received solar power 5 to 7 hours in each day with rate 4 to 7 kWh/m^2/day and received 300–330 days in a year. India has the seventh rank in larger energy production and fourth position in higher energy consumption worldwide. Currently, nearly 840 million Indians are completing his energy needs by biomass (Sahoo, 2016). Due to the fast-growing Indian economy requiring extra energy resources such as solar electricity for complete his future energy needs. Solar energy resource and temperature profile variation between India and Jalandhar city are shown in figure 1. Our experiments were performed near NIT Jalandhar which situates in Punjab state in India. The suitable amount of solar radiations is available throughout the years with average solar radiation rate 4.6 kWh/m^2/day. This city located (31.33 latitudes & 75.58 longitudes) on the Indian map and its 243m above sea level. Monthly and hourly change in Jalandhar city solar energy intensity profile is shown in figure 2. Environmental parameter such as humidity, temperature and dew point are varying in the experimental day which shown in figure 3.

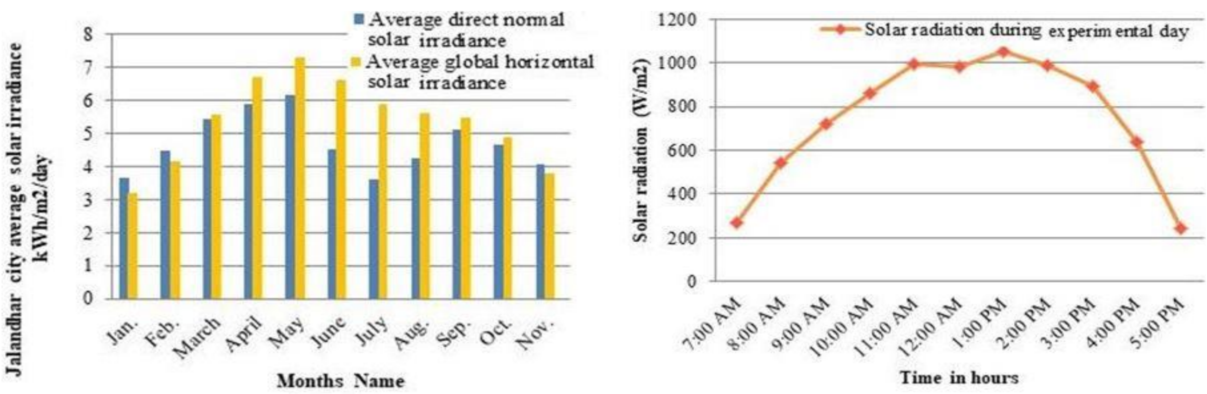

Fig. 2. Monthly and hourly change in Jalandhar city solar energy intensity profile (Weather Jalandhar, 2018).

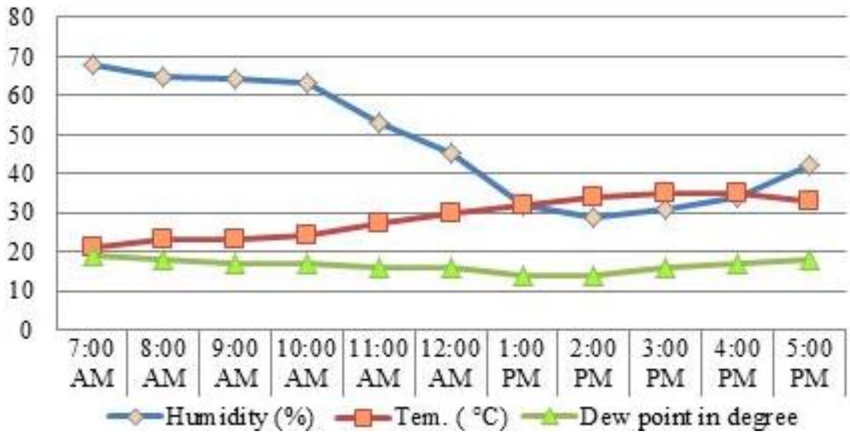

Fig. 3. Environmental parameter (humidity, temperature and dew point) profile in the experimental day (Weather Jalandhar, 2018).

3. Experimental setup used

Sustainable development with lower energy consumption in the transportation sector proves the greatest challenge in current time. Solar hybrid electric vehicles with a cooling chamber are gaining popularity worldwide due to their lower pollution and less operating cost of transportation (Mathiesen et al., 2015). These have better fuel economies compared to other types of vehicles and it needs further research advancement in this area to archives higher technical performance at a lower price. Due to rapid population growth in the Asian countries especially India, China, and South East Asia requires better food security to complete the foodstuff needs of his country peoples. These solar hybrid small electric trucks are a better option for effective optimization of the food supply chain and are also minimize the foodstuff wastage in the transportation of perishable products in the cold chain. These electric trucks require less maintenance and fit for retailer distribution centers. Today these type electric vehicle use more popular in the transportation of poultry farm products, dairy products like ice cream or milk, fast food items, bakery, cold chain products and is also used in entering city advertisement. In this experimental setup used four solar panels which were connected in series to receive 48V DC. Each solar panel produced 12V and I_{sc} (9.053A) when it tested under standard test conditions such as irradiance of 1000 W/m^{2}with cell temperature 25 °C as shown in figure 5. These panels fitted on hybrid vehicle roof to receive the maximum amount of solar radiation during sunny days. The solar charge controller (MPPT) has the capacity to control

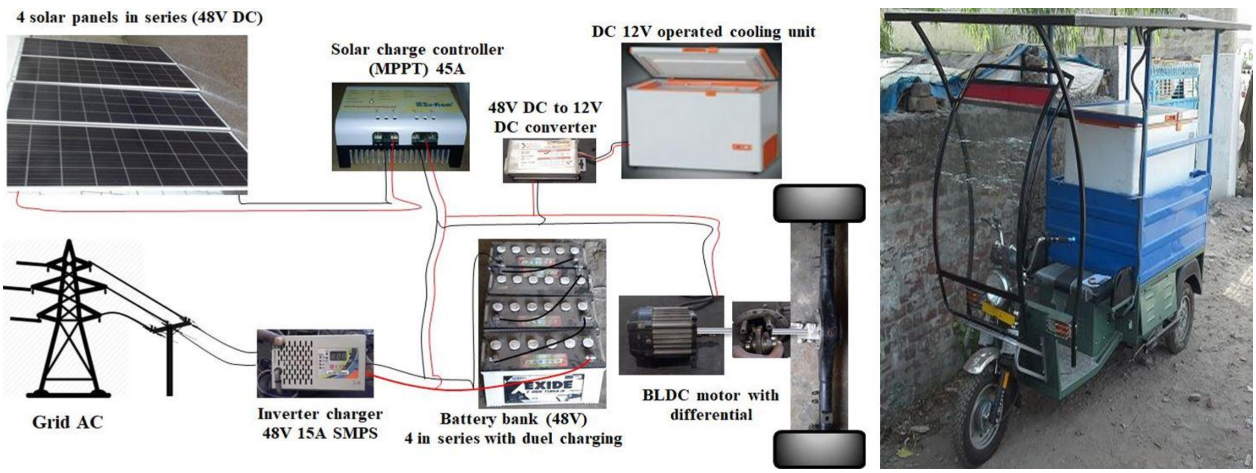

Fig. 4. Schematic and photographic view solar operated mobile refrigeration system (SMRS).

up to 45A DC was used to receive the maximum power output from solar panels; it's used for charging the battery bank in the day time. The battery bank has four batteries which were connected in series as shown in figure 4 and each battery capacity was 105Ah (12V). These four batteries (Exide E-ride tubular) were purchased from Exide company seller. This battery bank has a dual mode of charging in which first energy resource was solar energy (day time charging) and the second charging mode was grid electricity (for any time charging). The inverter type charger was used to charge the battery and its capacity was 15A (48V). This SMPS charger was using 7 to 8 hours' time for full charging (100%) in the battery bank. The BLDC motor has the capacity (1000W) which is used to supply energy for motion in rear wheels.

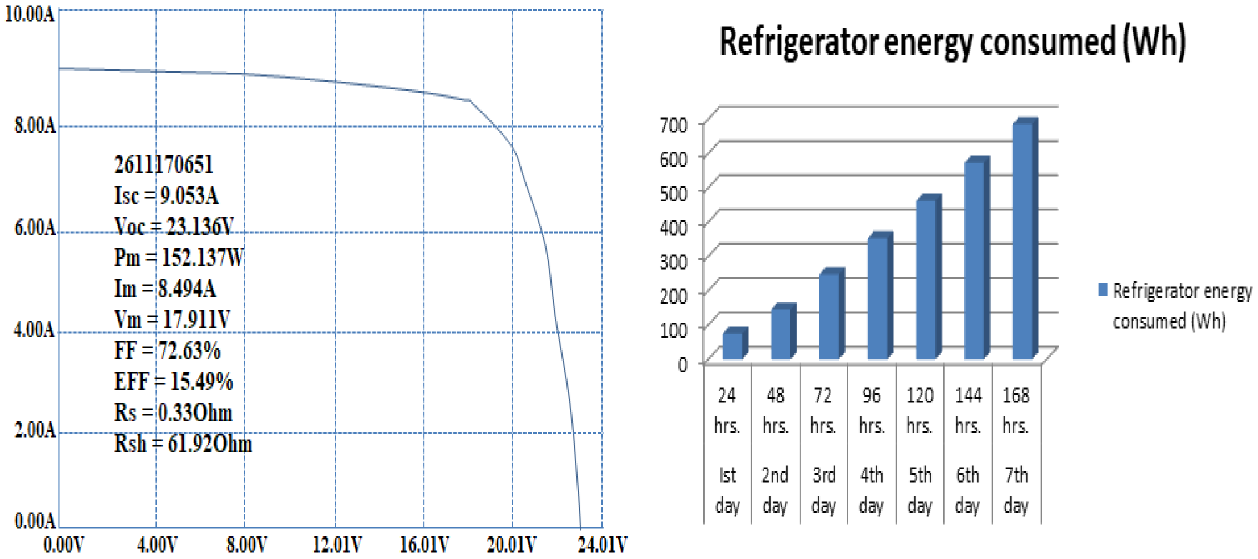

Fig. 5. Performance test of single solar module (150W) use in the experimental setup.

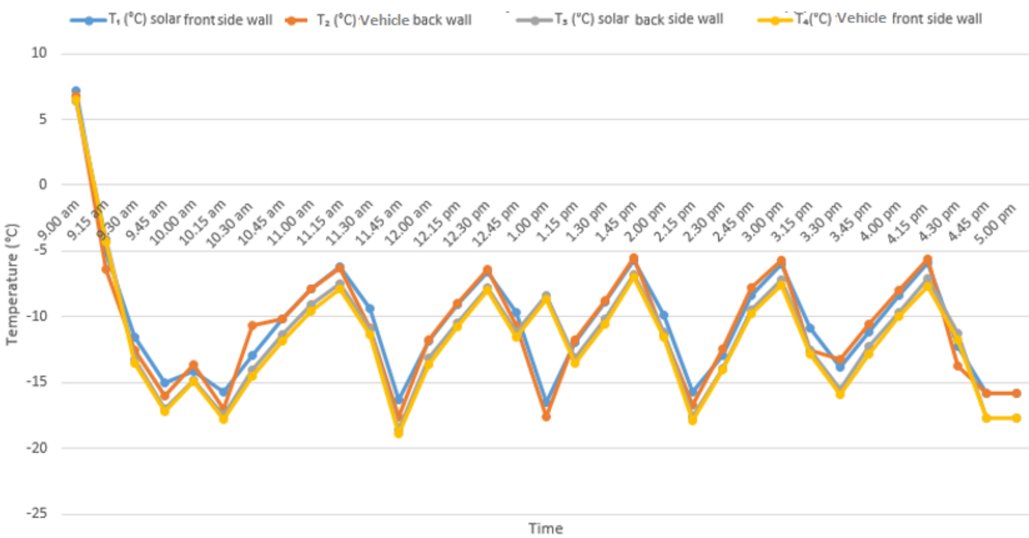

Fig. 6. The temperature profile of the cooling chamber with time in a no-load condition.

Table 1. Light commercial vehicle use in the market with a source of energy.

Name of component used and number	Parameter name	Specification
Four Solar panels connected in series	Capacity (W_P)	150 W
	Module volt (V)	12
	Width (W)	666 mm
	Height (H)	1483 mm
	Thickness (T)	35 mm
	Tolerance	+/- 5%
	Module weight	11 kg
	Cell in series	(9×4) 36
	V_{oc}	21.5 V
	I_{sc}	8.75 A
	$P_{Max.}$	150 W
	V_{pm}	18 V
	I_{pm}	8.33
	FF	>0.70
	Efficency (η_{pv})	>15.0 %
	Max. system voltage	1000 V
One charge controller (MPPT)	System voltage	24/48 auto recognition
	Max charge/ load current	45A
	Efficiency	92%-96%
One DC-DC converter	Voltage converting	48V DC to 12V DC
One cooling chamber (240 litters)	Dimensions of the outer cabinet	1145 mm×850 mm ×690 mm
	Inner dimensions	900 mm×673 mm ×440 mm
	Operating voltage	12V or 24V DC (normal)
	Temperature range	-16 to +6ºC
	Ambient temperature range	10 to 45ºC
	Refrigerant used	R-134a (eco-friendly)
	Door type	Top opening
	weight	58 Kg
	capacity	240 L
	Insulation	Polyurethane (12 cm thick)
	Compressor type	DC compressor
Four batteries connected series	Rated output	105 Ah, 12V
	Depth of discharge	80% (First 1600 cycles)
	Overall efficiency	62%
One DC motor used	Related output	1000 W
	Motor controller output	1000 W
SMRS vehicle	Wheelbase	2105 mm
	Overall length	2765 mm
	Overall width	990 mm
	Overall height	1050 mm
	Cargo box dimensions	1295 mm×945 mm×600 mm

Vehicle weight	390 Kg (without PV & cold storage unit)
Seating capacity	One driver
Estimate range	100 km (without solar) + 20-28 Km (with solar)
Maximum speed	25 km/hour
Climbing ability	20 % grading
Rating output	1000 W DC motor
Brake	Drum type
Charging time	100 % in 8 hours
Tire size	3:0-12
Wiring harness	1" heavy duty waterproof
Charger	48V 15A SMPS charger
Body material used	High-grade steel
Load capacity	310-380 kg

48V DC to 12V DC converter was used to supply power in the refrigerating unit. The refrigerating unit of this vehicle was operated continually for 3 days if we used the full charging battery bank. The refrigerating unit of this truck was 240 litter storage capacities and he was 40W cooling capacity. This refrigerating unit was suitable to use in between the temperature range 0°C to -16°C. Refrigerating unit power consumption and temperature change profile is shown in figure 5 and 6. Technical specification of solar operated mobile refrigeration system is shown in table 1. During the performance analysis test on SMRS vehicle, we checked the effect on battery discharge rate and vehicle speed with increasing load; its effects are shown in figure 7. Solar power meter (Amprobe solar -100) was used to measure solar power (W/m2) in the experimental day. Four digital watt meter (DC PZEM-051) was used to measure current, power and energy flow. Digital LED Tachometer with Proximity Switch Sensor (HITSAN 4) was installed to measure the wheel speed of the vehicle.

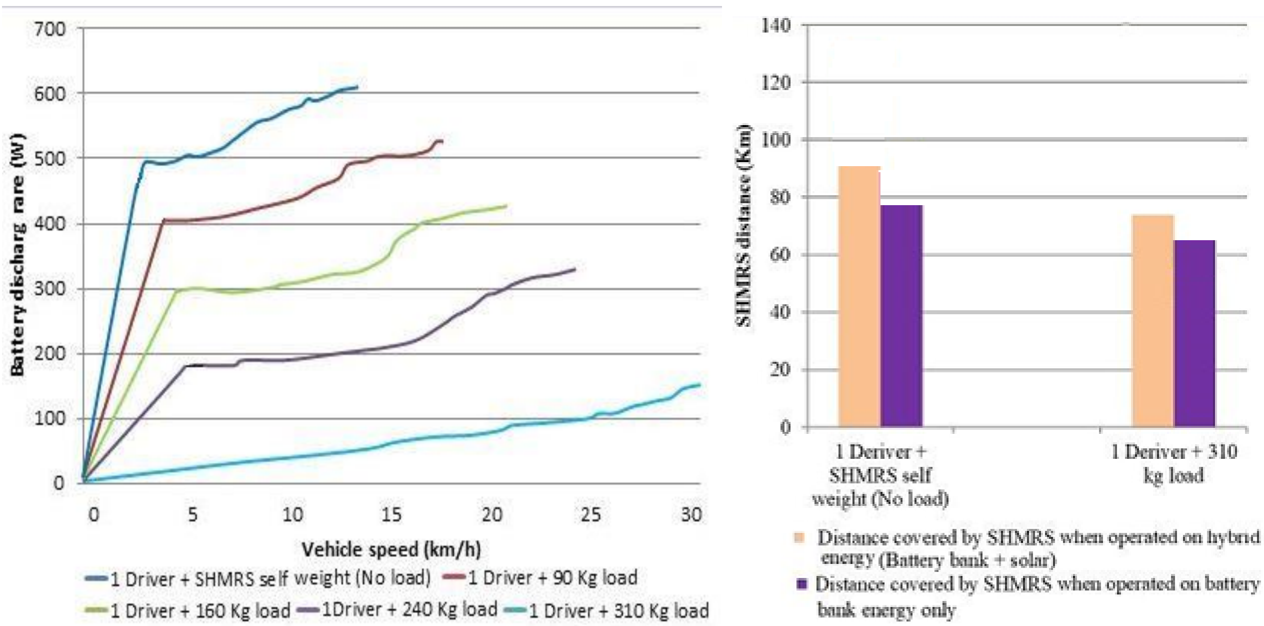

Fig. 7. Effect on battery discharge rate and vehicle speed with increasing load.

Three thermo-hygrometer (-35ºC to 75 ºC, 5% to 95% RH value) was used for measure temperature and relative humidity inside and outside of the cooling chamber.

4. Conclusions

This study investigates on the solar operated mobile refrigerating system or small electric trucks used in urban foodstuff transportation. This type of vehicle provides economic and environmental benefits during commercial delivery as compared to gasoline trucks. In this research paper focuses on a key parameter that reduces energy consumption and reduces overall intercity cost of cold chain perishable products transportation. SMRS provides additional benefit such as V2G which completes house energy needs during pick summer time when frequently cuts occur in grid electricity. This SMRS vehicle was operated on the dual mode of energy. After 7 to 8 hour night time charging the battery bank, SMRS covered distance nearly 75 to 86 Km with 310 – 360 kg load without supply solar energy. Due to utilizing solar energy in SMRS during experimentation its rise cruising range of this vehicle 12-18 km. Refrigerating chamber used in this vehicle has 40 W cooling capacity and its consumed energy 107 Wh/day at 26ºC ambient temperature. Power consumption of the refrigerating chamber was increasing with a rise in ambient temperature. The refrigerating chamber was operated for 7 days in one-time battery bank charging. The analysis result of this vehicle was showed clearly, the performance of SMRS was improved in term of acceleration and maximum speed. The hybrid technology used in SMRS or small electric truck is also applicable to other cities locations worldwide.

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