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Organic Photoelectric-Supercapacitor Power Source of Electric Vehicle

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Abstract:
The drawbacks of the electric vehicle are: battery pack increased weight, limited range and required additional electricity generation source to charge the batteries. The contribution of the coal plant to the production of electricity is 57% and emissions 1.4 kg / kWh, while gasoline 35% and 1.2 kg / kWh respectively. Thus, the development of an energy-boosting system for EVs is inevitable. The purpose of this study is to present a laboratory scale organic photovoltaic-supercapacitor (OPSC) power cell model as the mobile renewable energy source of electric vehicle. The laboratory scale organic photoelectric-supercapacitor (OPSC) has been developed using C-ZnO / CuO doped polymer and carbon fiber to generate electricity from solar-heat and storage. The OPSC has considered as the roof panel of EV and it has tested at a solar temperature of 30^0C. The test results show that the energy conversion efficiency (ηec) of 19%, voltage (V_{oc}) 2800 mV, current density (J_{sc}) 522 mA/cm^2, capacitance (C) 20.15 µF/cm^2, energy density (E_d) 120 Wh/kg, and power density (P_d) 29 kW/kg. It would be able to reduce EV battery size by 15%, weight 7.5% and battery charging power 9%. Furthermore, the OPSC-EV roof panel would contribute to the reduction of greenhouse gas (GHG) emission 25% and help transport the population with a low level of carbonization.

Keywords : Electric vehile energy system, Organic photovoltaic-supercapacitor; energy storage, Emission reduction, Low-carbinization.

NOMENCLATURE

Bandgap energy	E_{ev}	:V
Short circuit current density	J_{sc}	: A/m^2
Open circuit voltage	V_O	: V
Charging voltage of the capacitor	V_{sc}	: V
Conversion efficiency	η_{CE}	: %
Fillining factor	FF	: %
Energy store	E_{stor}	: J
Light energy received	E_{lig}	: J
Total energy store	E	: J
Charging time	T_c	: S
Solar power	P_{ligh}	: W
Regenerative braking power	P_{reb}	: W

1. INTRODUCTION

Energy conversion and storage involve physical interaction at the surface or interface, so the specific surface area and surface energy play a very important role. The surface impacts are not limited to the kinetics and rate only, the surface energy can have appreciable or significant influences on the thermodynamics of heterogeneous reactions occurring at the interface and the nucleation and subsequent growth when phase transitions are involved. Nanomaterial offer many advantages in energy conversion and storage applications. The smaller dimensions of nano-materials may also offer more favorable mass, heat, and charge transfer. Nano-materials also introduce new challenges in the application of energy conversion and storage. For example, large specific surface area offers more sites for charge recombination in

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photovoltaics (Cahen et al., 2000) and smaller pores may limit the penetration of electrolyte ions in super-capacitors (Fernandez et al., 2009).

The basic principle of the design of photovoltaic cells is to increase the optical absorption of the active layer and / or reduce the loss of electrons during transportation. Nanostructures can be used to improve the characteristics of photovoltaic cells by (i) creating new mechanisms, such as the effect of multiple exciton generation in quantum dots, (ii) improve the transport and / or collection of electrons through the use of nanostructures. Adapting nano-materials to optimize light collection and electron transfer is an effective means of creating highly efficient solar cells.

Organic solar cell integrated with ultra-capacitors to generate energy from solar energy and store. The compound can be considered as an exclusive EV body panel that contributes energy (Carlson et al., 2011, Snook et al., 2011, Rani et al., 2008). Advanced composite materials have gained popularity in structural applications due to their important properties, such as corrosion resistance, lightweight and mechanical strength (Rahman et al.,2015, Rahman et al., 2018). Organic compound integrated power generation, conversion and storage have recently attracted more attention (Yang et al., 2013; Wee et al., 2011; Guo et al., 2012). As an integration platform, a printable solid-solid integrated device consisting of a single-wall nano-tube network (SWNT), a polymer solar cell and a supercapacitor were studied (Wee et al., 2011). The performance of the CdTe / CdS glass substrate solar cell was studied (Won et al., 2015) and the solar energy conversion rate was reported as ηec of 10.9%, JSC of 25.8mA / cm2, VOC of 720 and FF 58.7%. Silicon microcrystalline solar cells have the highest ηec of 30% and dominate as commercial photovoltaic solar cells [Miyazawa et al., 2018]. However, economical, this is not feasible due to its inflexibility, higher and heavier production cost. (Daniel, et al., 2016).

Utra-capacitors are called electrochemical capacitors (CEs) [Yang et al., 2011], recently considered promising energy storage devices and have been applied in various technologies, such as hybrid electric vehicle power supply devices (HEVs) (Simon and Gogotsi, 2008). Carbon nanotubes and graphene sheets have played an important role in the development of super-capacitors [Zhang et al., 2009; Lu et al., 2010]. Carbon-based materials such as carbon nanotubes, porous carbons and graphenes are commonly used as electrode materials for super-capacitors (Aaron and Aiping, 2011). The carbon nanotubes (CNTs) has a great interest in high-performance supercapacitors (Dai et al. 2012). CNTs with a high specific aspect ratio (SWNT > 1600 m2 / g and MWNT > 430 m2 / g) (Liu et al., 2010), ratio of lateral size to thickness (Zhu et al., 2011) and excellent mechanical properties (Lee et al., 2008) and carrier mobility (15,000 cm2 / Vs). The authors (Xia et al., 2009, Liu et al., 2010) have studied SC fabrication using CNT based nano-composite ink and graphene / conducting polymer composite as active electrode materials as well as nano-cellulose as separator. The EDLC has a tendency for relatively fast self-charging in three mechanisms: overcharging, side reactions and ohmic leakage (Liu et al., 2010). Theoretically, the double-layer capacitance value of a graphene electrode can reach up to 550 F / g, the highest value of intrinsic capacitance among all carbon-based electrodes (Xia et al., 2009, Liu et al., 2010], as was a supercapacitor with an ultrahigh specific energy density of 85.6%, and a specific supercapacitor with a specific capacitance of 135 F/g and energy density of 136 Wh/kg at 800C (Liu et al., 2012). Table 1 has presented the performance of the high efficient organic solar cell. This study has presented a photovoltaic-supercapacitor model to generate electricity from solar heat and store. In addition, the OPSC will become the storage of regenerative braking energy (RBE) of EV.

2.0 METHODOLOGY

An organic-photovoltaic power cell has been made with C-ZnO doped polymer solar cell, series resistance (R_s for the C-ZnO nanowires), CuO doped polymer supercapacitor, and resistance of the electrodes (R_{CF} of the CF). During the charging period with a solar temperature of 30°C, the energy conversion and storage efficiency as a function of time of charge, t is defined as η_{ecs} (t) = E_{store}(t)/

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E_{light} (t) where E_{store} is the energy stored in the supercapacitor at time t and E_{light} (t) light energy received by the solar cell. The light energy, E_{store} (t) =P_{light} * t where P_{light} is the solar power, the solar power in this tudy is considered as 1000W/m^2. The energy store can be defined as ,

$$E_{stored}(t) = \int_0^t v_{sc}(t) \cdot t_c(t)\, dt \qquad (1)$$

where, v_{sc} (τ) is the charging voltage of the capacitor which is developed due to the variation of the solar temperature and the fill factors of the cell and $t_c(\tau)$ is the charging time of the supercapacitor with solar power. Since the supercapacitor also considered to store the regenerative braking energy, the total energy stored to the supercaacitor can be defined as,

$$E_{T(stored)}(t) = \int_0^t v_{sc}(t) \cdot t_c(t)\, dt + \int_0^t P_{rgb}(t)\, dt \qquad (2)$$

where, $P_{rgb}(\tau)$ is the regenerative braking power of the EV which generates by the motor during deceleration and downing from the slope. The regenerative braking energy (E_{rgb} (τ)) is considered as 24% of ½ mV^2 where V is the speed of the vehicle in m/s. The current density can be defined as,

$$J = \left[q\left(N_n \mu_n + N_p \mu_p\right) E + \left(D_n \frac{\partial N_n}{\partial x} + D_h \frac{\partial N_p}{\partial x} \right)^{(e)} \right] \qquad (3)$$

where, n represents N-type and p represents P-type, μ the electron mobility of composite, D is the diffusion coefficient, e the electron = 1.6×10^{-19}C. The diffusion coefficient is estimated by using Einstein equation, N_n and N_p are the number of free electron. The diffusion coefficient is estimated by using Einstein equation, D=μkT/q, where k is the Bolzmann's constant and q is the charge in Columb. While, based on the Culomb's law, electric field E induces by an isolate charge q at any point of the photovoltaic panel which can be defined as E = [$q/4\pi\varepsilon d^2$] where D is the thickness of the composition of photovoltaic ZnO and polymer and ε is the electrical permittivity of the photovoltaic elements.

The efficiency of the energy conversion of the OPSC can be defined as,

$$h_{ece}(t) = \frac{\int_0^t V_{sc}(t) * i_c(t)\, dt}{P_{light} * t} * 100\% \qquad (4)$$

The time of full charge can be estimated as, $t_c = CV_{oc}/I_{sc}$ where, V_{oc} is the open circuit voltage, I_{sc} is the short circuit current. The voltage generation of the solar cell can be estimated as, $V_{pv} = V_{sc} + R_s I_{sc} = Q_{sc}/C_{sc} + Rs\, I_{sc}$.

2.0 DEVELOPMENT OF OPSC

The organic photovoltaic-supercapacitor (OPSC) has been designed and developed for the EV as a body panel to generate electricity from solar energy and store. It is made with carbon zinc oxide (C-ZnO) and copper oxide (CuO) conductive polymer, carbon fibre (CF) and dielectric as separator/salt aquous electrolyte.The basic design principle of OPSC is to enhance the optical absorption and/or reduce loss during electron transport to cenvert the solar energy into electric energy and store. The nano C-ZnO structure is employed to improve the performance of OPSC by increasing the exciton generation effect in quantum dots, creating large surface area, generating unique optical effects and improving the electron transport and/or electron collection. The C-ZnO nanostructure is made in a shape of nanowires which has less defects in the material. Therefore, this single crystalline phase causes the much higher electron mobility and highly efficient in electron transport. Furthermore, ZnO nanowire array achieved considerably higher photocurrent about 55-75% than the ZnO nanoparticle film and diffusivity 0.05-0.5 cm^2s^{-1}, which is several hundred times higher than nanoparticle films of TiO_2 and ZnO. CuO doped polymer is employed in polymer reinforced with CF to increase the electron collection (Qifeng et al., 2013)..

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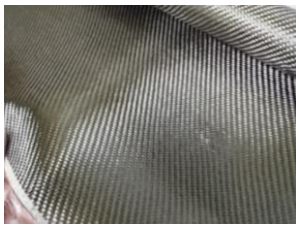
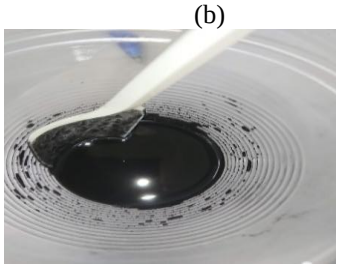


(a)

(b)



(c)

Fig.1: Materials for OPSC (a) Carbon fibre (b) mixture of nano ZnO, ER and Hardener; (c) mixture of CuO, ER and hardener

CF fabrics derived from π-Carbon (240g / m2) 0.25 mm thick were used for the development of OPSC (Fig.1). The CF acts like a common OPSC electrode. To enlarge the specific surface area of the CF electrodes, the CFs should be activated by recording in HNO3 at 90 ° C for about 2 hours on the side that must be in contact with the dielectric. Epoxy resin and hardener were selected based on their compatibility with carbon fibers. The transparent epoxy resin and hardener came in a package with a recommended mixing ratio of 2: 1 and a complete curing time of 24 hours between 25 ° C and 30 ° C, provided by π-Carbon Malaysia. The CF electrodes were reinforced with nano ZnO epoxy for the negative electrode to facilitate high electron mobility as a type n semiconductor with a bandgap energy of 3.2 eV to 3.4 eV and is enhanced to 3.5 eV through the application of 5% π-carbon, and epoxy-filled nano-CuO to the positive electrode to facilitate bore / positive charge movement as a p-type semiconductor with a band range from 1.2 eV to 1.8 eV (Dhara et al, 2016). By incorporating these nanoparticles into the opposite electrodes, they increased the conductivity of the CF electrodes. The zinc oxide (ZnO) nanoparticles (size 10 nm) were supplied by Chemetal SDN, BHD, Malaysia. The copper (II) nanoparticles (CuO) (size 50 nm) were from Sigma-Aldrich. Both samples come with the risk of handling P273 and the environmental risk H411. The dielectric film was placed between the ZnO doped ER added to one side of the CF and the CuO doped ER added to the side of another thin CF layer. The sample of the OPSC laboratory scale has shown in Fig.2.

Fig. 2. Laboratory scale OPSC.

2.1 Preparation of P-type and N-type Semiconductor for OPSC

Different mixture compositions were made and tested accordingly to justify the best mixture percentages. All the composition has been taken in weight percentage (wt%). For example, a 10% mixture means 10g nano-particles was mixed with 60g epoxy and 30g hardener. The ratio of epoxy to hardener is always 2:1 in all the cases as recommended by the manufacturer of epoxy resin. The different mixture has been made to identify the best composition for the OPSC (Table 1).

Table 1. Composition of nano conductive powder for OPSC.

Electrode	**Mixture (M)**			
CF & P-type SC	**M1** (wt.%)	**M2** (wt.%)	**M 3** (wt.%)	**M4** (wt.%)
Epoxy+hardener	95	90	70	64
ZnO	5	10	30	30
π-carbon	0	0	0	6
CF & N-type SC	**M1** (wt.%)	**M2** (wt.%)	**M 3** (wt.%)	**M 4** (wt.%)
Epoxy+hardener	95	90	70	64
CuO	5	10	30	30
π-carbon	0	0	0	6

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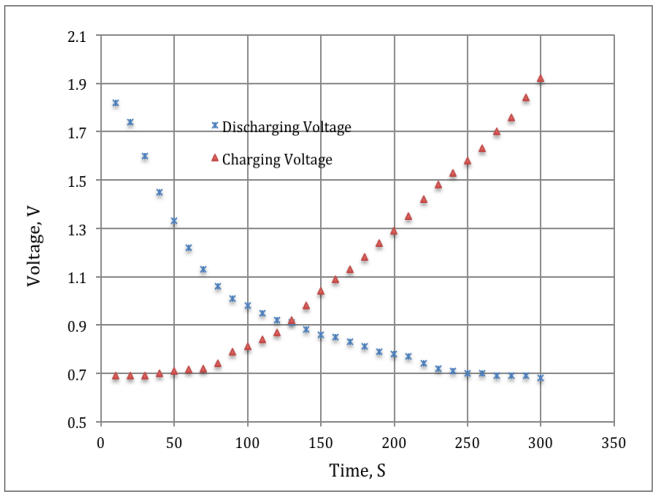

Fig. 3: Charging and discharging voltage of OPSC at a solar temperature of 30^0C.

Organic solar dielectric capacitors and EDLCs were made in two different ways. For dielectric capacitors, a flat mold was made to which non-sticky film was attached. Then, a carbon fiber adhesive was placed in the mold with the wires placed in a corner at the top and the mixed C-ZnO-epoxy was brushed evenly. The epoxy mixture is spread over the fibers by pressing it manually by the brush. This became the negative electrode of the photo-ultracapacitor, as C-ZnO acts as a n-type semiconductor. Then, the 70 g / m² paper dielectric was placed on top and pressed with weight and then allowed to cure for 24 hours. After the carbon fiber of the negative electrode hardened, the next layer of wired carbon fiber adhesive was placed and the CuO-filled epoxy mixture was glued to it. Then, the same process was followed as the epoxy layer filled with ZnO until curing. This became the positive electrode of the photo-ultracapacitor, as CuO acts as a p-type semiconductor. For 1 sample, only 1 type of mixture was used, for example, 5% of the sample contained 5% ZnO in the negative electrode and 5% CuO in the positive.

EDLC, on the other hand, followed a similar process, except that the electrodes were made separately. The separator impregnated with aqueous Na2SO4, impregnated with an electrode, is filled with electrodes C-ZnO CF polymer paste and CuO CF polymer paste. The charges are stored at the electrode-electrolyte interface on the EDLC. When the EDLC is charged, the electrolyte ions are moved to the opposite charge surface of the electrode to compensate for the electron charge. The energy accumulates electrostatically in an electric field between the ionic layer and the surface of a charged electrode since the charges do not have direct contact with the electrode surface due to the presence of a layer of solvent molecules between them. Energy is released during discharge as the ions move in the opposite direction.

3.0 RESULT AND DISCUSSION

The number of samples of OPSC, size of 0.0045 m^2, mass 9g (all samples) and mass 12g of 30% ZnO/CuO double layer CF, has been with different composition of C-ZnO and CuO and dielectric materials (20g, 70g, and 80g non-aquous paper film and Na_2SO_4soaked paper film). Initially the terminals of the final sample of OPSC for different composition has been short circuited to be ensured no charge was stored in OPSC. Then it has been tested both indoor and outdoor environment. The OPSC indoor testing has been made using the fluorescent lamps with temperature of 27°C and outdoor was in solar temperature of 32^0C and 34°C at 13.20 and 13.50 Malaysia time respectively. A multimeter was attached to the terminals of the sample to be tested. The results has been recorded in every 10 seconds until 5 minutes for each of the samples at solar temperature in the range of 20-34°C at samples were taken at an interval of 10 seconds for 5 minutes to investigate the performance of OPSC at a solar temperature of 20-34°C.

The charging discharging behavior of the OPSC has shown in Fig.3 which exhibits that the OPSC charging time and discharging time almost same. The OPSC has charged 0.2 V in 190s and 1.0V 200s while discharged 1.0V in 190s and 0.2V in 200s. The result indicates that the discharging time is faster than the charging time. The results shows that the performance of the OPSC increases significantly at solar temperature of 32 and 34°C in terms of power density (Fig.5), State-of-charge

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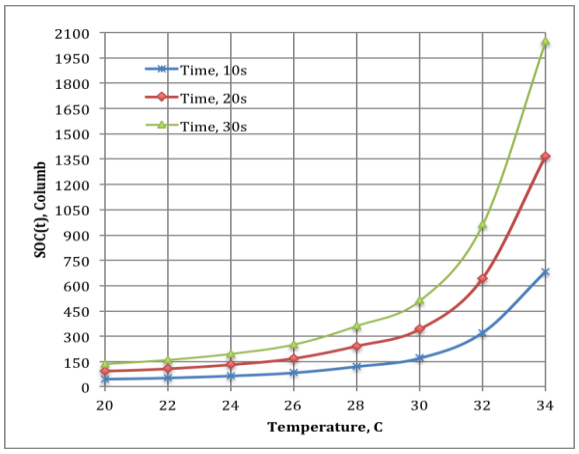
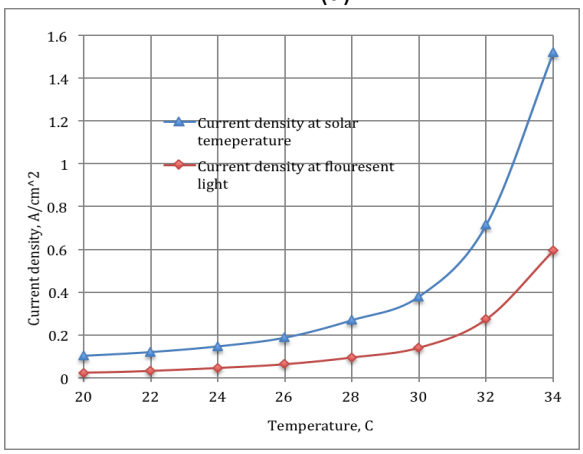


(a)



(b)

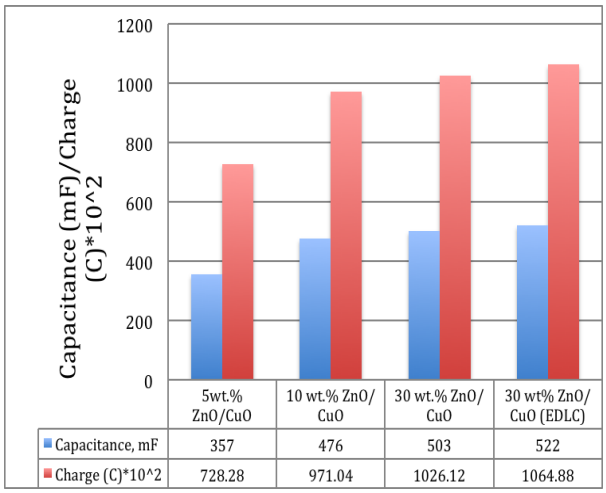
Fig. 5: Performance of OPSC during charging.

(SoC) (Fig.5a) and current density (Fig.5b). The SOC has been measured with a solar temperature of 34°C for 10s, 20s, and 30s. The SOC exhibits better results at a solar temperature of 34°C for 20s. It is due to the increment of electron diffusivity and mobility by the C-ZnO-PR/CF and collection by the CuO-PR/CF. The OPSC current density (Fig.5b) has been tested at temperature of 30°C using the flouresent light and a sloar heat. The open circuit voltage changes significantly with increasing the temepature. Mathematically VOC can be defined using the equation (Nayak e al., 2012):

$$V_{oc} = E_g - \frac{\sigma_n^2 + \sigma_p^2}{2kT} - kT \ln\left(\frac{N_n N_p}{np}\right) \quad (5)$$

where, q is the charge, E_g is the energy gap, σ_n (σ_p) is the width of Gaussian density-of-states for the acceptor fullerene (donor polymer) ($\sigma \approx 100$ meV at room temperature, N_n (N_p) is the effective conduction band (valence band) density-of-states, n (p) is the free electron (hole) concentration.

Performance parameters of the OPSC such as open circuit voltage (V_{oc}), short-circuit current (J_{sc}), state-of-charge (SoC) and power density (P_d), energy density has been measured for two different smaples (i) paper film dielectric; (ii) Na_2SO_4 aquous soaked paper film which is considered as EDLC. The average power conversion efficiency of 11 samples with different composition was found 11.5%. It is concluded that the FF fall drop, leading to the reduction of Jsc, Voc and conversion efficiency.



	5wt.% ZnO/CuO	10 wt.% ZnO/ CuO	30 wt.% ZnO/ CuO	30 wt% ZnO/ CuO (EDLC)
Capacitance, mF	357	476	503	522
Charge (C)*10^2	728.28	971.04	1026.12	1064.88

Fig.6: Capacitance and charge of OPSC.

Voltage readings of 70gsm paper sample show that 30% of ZnO/CuO & 6%of C composition has the highest voltage and voltage drop respect to time is the lowest compared to other composition. The current density level at 0s indicates the J_{sc} of the OPSC. It dicharges over time until 100s . The decrement of current decreases was incurred very high at time between 0-10s which is the characteristic of capacitor. Fig.10 shows that the energy storing into the OPSC increases slowly while it discharge energy very fast in 0-20s. However, after 80-100s it was about 50 kJ/m^2.

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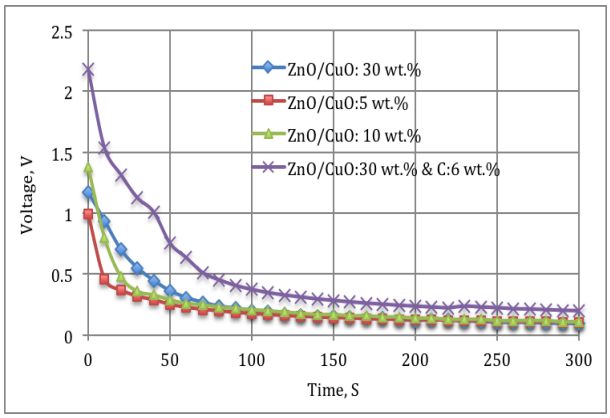
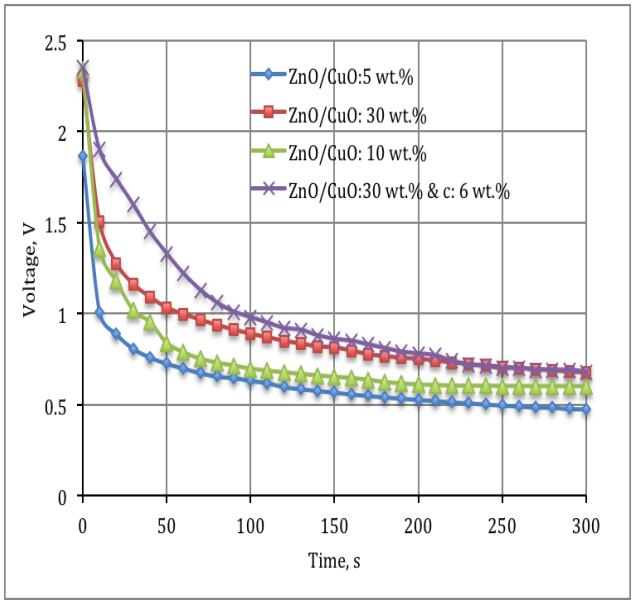
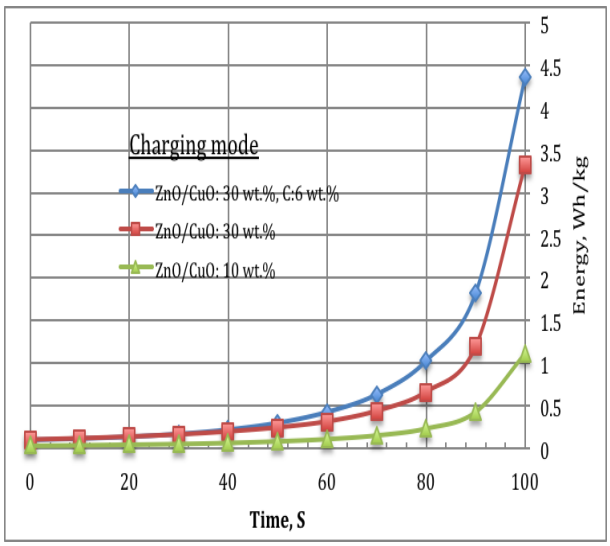


(a)



(b)

Fig.7: Discharge voltage of OPSC (a) paper film dielectric (b) Na_2SO_4 soaked paper dielectric (EDLC).



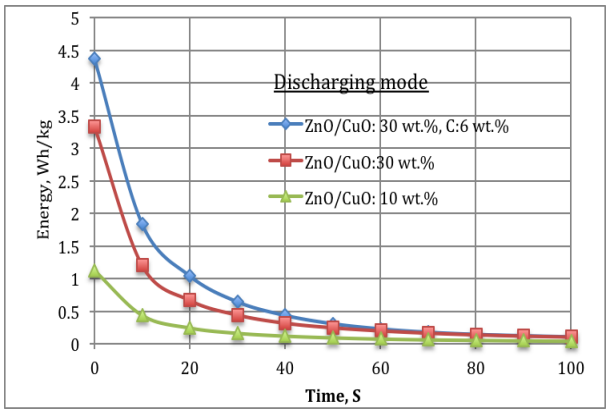


Fig.8: Energy store at OPSC of Na_2SO_4 soaked paper dielectric.

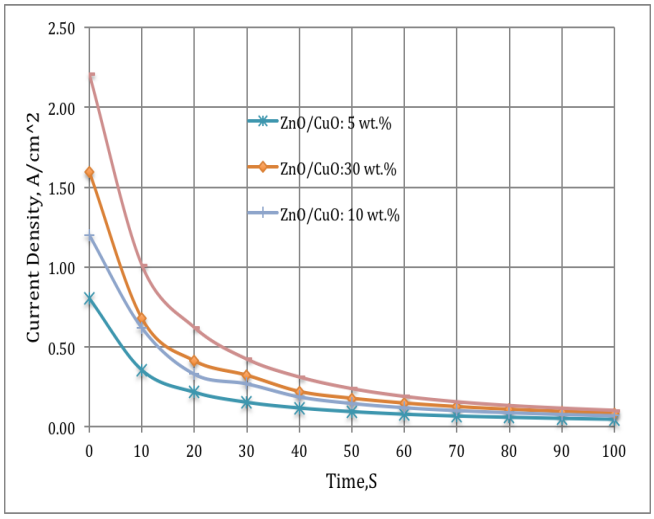


Fig.9: Current density during discharging.

Fig.10: Energy density during charging and discharging for OPSC with Na_2SO_4 soaked paper dielectric.

4.0 CONCLUSION

The OPSC will have solar energy conversion efficiency about 20-22% at a solar temperature of 25-30º, power generation of 2800W/day, power density of 33 kW/kg, energy density 130 Wh/kg, capacitance of 20.15 μF/cm^2 and discharge times 10 times longer than the charging if it is developed as roof size of EV about 2.4 m^2. The output of the OPSC would be able to reduce the EV battery size by 10% and weight about 7.5%. In addition, the OPSC-EV would contribute on the reduction of manufacturing cost of 10% by saving USD1,000 from reducing the battery size. It would be able to

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reduce the green house gas emission of 25% (based on the consideration of greenhouse gas emission 2.31kgCO_2/litre of petrol).

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