A review on Supercapacitors: types and components

Noor I. Jalal*, Raheek I. Ibrahim, and Manal K. Oudah
Electromechanical Engineering Department / University of Technology – Iraq / Baghdad- Iraq

*Corresponding author email: eme.19.11@grad.uotechnology.edu.iq

Abstract. The importance of Super-capacitors (SCs) stems from their distinctive properties including long cycle life, high strength and environment friendly, they are sharing similar fundamental equations as the traditional capacitors; for attaining high capacitances SC using electrodes materials with thinner dielectrics and high specific surface area. In this review paper, all types of SCs were covered, depending on the energy storage mechanism; a brief overview of the materials and technologies used for SCs is presented. The major concentration is on materials like the metal oxides, carbon materials, conducting polymers along with their composites. The composites’ performance was examined via parameters like capacitance, energy, cyclic performance power and the rate capability also presents details regarding the electrolyte materials.

Keywords: Super-capacitors, metal oxides, Electrolyte, EDLC, Pseudo-capacitors, hybrid super-capacitors

1. Introduction

Energy is a significant topic, as energy resources are of high importance in the residential and industrial applications. Owing to rapid growth of the global economy, a main worldwide increase in the fossil fuels’ depletion resulted in 2 major concerns: the first one is the exhaustion regarding current supplies of fossil fuels, while the second was associated to the increase in greenhouse gas emissions, particularly, and generally the environmental pollutions. Therefore, there is a high importance in developing and commercializing renewable sources of energy which were environmentally friendly, and their associated technologies were globally developed [1,2]. The consumption and production of energy, which depends on the fossil fuels’ combustion, might have a considerable impact on environment and global economy. Therefore, there were more needs for low costs, high performance and environmentally friendly storage devices with regard to renewable energy [3]. SCs are emerging with promising potential for applications among different energy storage device types. Because of their exceptional storage properties and power density, SCs have overriding significance compared to the other contemporary energy storage devices due to the fact that they have many advantages, like the high power density, long life cycle, high specific capacitance, high performance, environmental friendliness and versatile operating temperature. In addition, they have been quickly charged with quick power delivery and might be bridging the gaps between traditional condensers and batteries [4]. These benefits make it ideal for bridging power in the rural areas in which there weren’t public grids or in which there was high-costs of wiring as well as energy supply [5]. In many applications, SCs can also be used, such as wind power generation, photovoltaic generation, rail, electric cars, electric grid, etc. Because they are, lightweight and versatile, they are often used as power supplies with regard to portable devices including notebook computers, phones, digital cameras, and so on. SCs can be used in electric and hybrid vehicles to provide the high power density needed for short term acceleration in addition to energy recovery throughout braking, thereby save energy and protect batteries from rapid phase of high-frequency charging discharge (dynamic operation). Furthermore, the energy density and power density have been shown via Ragone plot (Fig. 1) [6, 7].
It can be seen from (Figure 1) that a battery is capable of producing an energy density of up to 150Wh/kg, about 10-times the capability of SCs. With regard to power density, the batteries have no ability for meeting SC values. Batteries are hardly exceeding 200W/kg, that is approximately 20-times less compared to the output related to predicted electrochemical capacitor. In addition, the batteries encounter limitations such as rapid output decreases because of the cold ambient temperatures or short charge discharge cycles. It is costly to manage and has a short life [8]. Currently, such SCs can’t be utilized for replacing the technology of batteries, yet they might be acting as replacements via offering instantaneous current needed for minimizing the current of battery with regard to temporary and momentary loss of power. In addition, the electrochemical SCs might be parallel mounted for compensating the temporary and momentary interruptions in large-scale battery units. This would dramatically minimize the excessive burden imposed on the batteries by short term interruptions. Presently, all SC researchers are concentrating on the way for minimizing the energy density, whereas maintains cycling stability, high power density and fast charge/discharge [9, 10].

2. Capacitors types
There are two types of capacitors the first type is Conventional capacitors these types of capacitors include 2 conducting electrodes which are separated via an insulating dielectric material. In the case where there is a voltage applied to the capacitor, and then the opposite charges will be accumulating on each electrode’s surface. Also, the separation of the charges was kept via the dielectric; therefore, generating an electric field which allow storing the energy via the capacitor, this is shown in (Fig. 2 a). There are fairly high power densities related to conventional capacitors, yet fairly low-energy densities in the case when put to comparison to fuel cells and electrochemical batteries. Batteries have the ability for storing more total energy compared to the capacitor, yet it has no ability for delivering it rapidly, indicating that it has low power density. At the same time, capacitors, are fairly storing less energy for each volume or unit mass, but what electrical energy they actually store may be discharged rapidly for producing a lot of power; thus, they have high power density [9, 11]. Supercapacitor (SCs) includes an electrolyte, 2 electrodes and a separator which is isolating (electrically) the 2 electrodes. Similar basic principles are governing conventional capacitors and SCs. Yet, they are incorporating electrodes with high surface areas as well as thin dielectrics which reduce the distances between electrodes. SCs have the ability for achieving comparable power densities. In addition, they have
many benefits compared to fuel cells and electrochemical batteries, such as short charging times, long cycle-life and shelf-life and high power density. SC’s schematic diagram is shown in (Fig. 2 b) [11].

![Figure 2. Schematic representation of capacitor type: (a) conventional capacitor ; (b) supercapacitor](image)

3. Supercapacitors types
Supercapacitor (SC) was divided into three groups based on the mechanism of energy storage as shown in (figure 3).

![Figure 3. Supercapacitors types based on the mechanism of energy storage](image)

3.1 Electrochemical double-layer capacitors (EDLCs)
EDLCs includes an electrolyte, two carbon based materials utilized an electrode as well as a separator. EDLC are either able to electro-statically store the charges or via a non-Faradic process that doesn’t need charge transfers between the electrolyte and electrode [13]. The electrochemical double layer is the concept of energy storage used by EDLCs. There was no accumulation of charges on the surface of
3.2 Pseudocapacitors
Type of supercapacitor with metal oxide or conducting polymer electrodes with high electrochemical pseudocapacitance material. The mechanism for storing charge is Faradaic mechanism, like oxidation-reduction reactions, involve charge’s transfer between electrolyte and electrode as shown in figure 4 (b). In the case of applying a potential to the pseudo-capacitor reduction and the oxidation happens on electrode material that includes the charge’s passage across a double layer, leading to the fact that the Faradic current pass through an SC cell. In addition, the Faradic mechanism involved in pseudocapacitors allows them for achieving great specific capacitance as well as energy densities in comparison to EDLCs [11, 16].

3.3 Hybrid Capacitors
Type of supercapacitor with asymmetric electrodes, one of them is majorly electro-static, while the other was the electro-chemical capacitance. In addition, the hybrid capacitors were a combination of performance properties which previously was unachievable. Also, they are combining the best features related to pseudo-capacitors and EDLCs into a unified SC. Even though hybrid capacitors were explored less compared to pseudo-capacitors or EDLCs, attempts were expanding in terms of creating enhanced hybrid capacitors and developing more precise quantitative models regarding the hybrid capacitors. In addition to the increase in the focus towards creating high energy and high cycle life SCs, the massive simplicity to tune the performance and design of hybrid capacitors led them to surpassing EDLCs as the major SCs class [17]. The mechanism for storing charge combination of the two Combine the two previous types as shown in figure 4 (b). Hybrid capacitors were divided into 3 categories differentiated via their electrode configuration: asymmetric, composite and battery-type.

3.3.1 Composite
The composite electrodes are incorporating carbon based materials with polymer conduction or metal oxides in a single electrode, indicating that the single electrode is going to have 2 mechanisms for storage, chemical and physical. Composites have 2 types: in the case when an electrode is made of only two materials, it is called Binary composites, but if it consists of three different materials, then it is called ternary composites [11].

3.3.2 Asymmetric: Asymmetric hybrid capacitors are combining the Faradic and non-Faradic processes via coupling a pseudo-capacitor electrode with EDLCs. In such way, the carbon material was utilized as a negative electrode, whereas either conducting polymer or metal oxide as a positive electrode [11].

3.3.3 Battery type: A rare combination of a battery electrode and SC electrode. This design illustrates the requirement for higher power batteries and high energy capacitors, combining the SC recharging times and battery properties, and achieves both battery and SC characteristics in one cell. Just a few studies on battery-type hybrids have been performed [11, 17].
Figure 4. Schematic diagram of Energy storage of SCs types: (a) (EDLCs); (b) pseudo-capacitors; (c) Hybrid capacitors [20].

4. Supercapacitor Electrode Materials

Electrode materials are of high importance in the performance of SCs. To get excellent SC performance results, the material must have high capacitance. The capacitance of SC is on the basis of effective surface area related to its electrode materials. Yet, not the whole effective area is totally available for the interaction of the electrolyte electrode, and therefore the electrode materials’ capacitance isn’t strictly proportionate to their effective surface area [18, 19]. Therefore, the electrochemically available area might be indicated as an active electrochemical surface area. In addition, the pore size related to conducting materials is determining the electrochemical active surface area that might be simply tuned via the use of nanostructures. The researches states achieving 0.7 maximum capacitance. The distance between the pores rises when the pore size will be increased; while there will be a decrease in capacitance [17]. Eventually, the capacitance, the region of the cross-section and the size of the pore depend on each other. For supercapacitors, the purity of the material is important, since it is greatly affecting their cycle life and leakage current. Furthermore, the impurities in electrolyte or electrode material are contributing to the SC’s unwanted leakage current as well as consequent self-discharge. While it is simple to build devices for which output is not significantly affected by self-discharge [18, 19]. On the basis of type of energy storage and capacity ranges required for a specific application, SCs might be manufactured from various materials, and by reference to the SC types indicated earlier, the electrode materials might be divided into 3 types on the basis of their use in hybrid capacitors, pseudo-capacitors and EDLCs, as shown in figure 5 [20]. the first is focused on carbon, that is providing 3000 m<sup>2</sup>g<sup>-1</sup> surface area with the ability for producing a capacitance of 145 Fg<sup>-1</sup>. Carbon-formed SCs were referred to as EDLCs. In addition, the second one is for SCs on the basis of redox reaction (pseudo-capacitors) where electrodes were made from electronically conducting polymers or metal oxides. Usually, their capacitance values are yielding between 300 and 400Fg<sup>-1</sup>, yet they have an issue of long-term stability giving just thousands of cycles over a wide range...
of voltage. Furthermore, a combination of pseudo-capacitance electrode and double layer electrode has been created in the third group are known as hybrid capacitors [21].

![Figure 5. Classification of SC, along with their electrode materials [20]](image)

4.1 EDLCs electrode materials
General electric engineers discovered EDLCs in series of experiments in the year 1957 with devices on the basis of porous carbon electrodes. After that, it has been indicated that energy is contained inside the carbon pores. Although they did not make much effort to improve it, The Standard Oil of Ohio, in the year 1961, unintentionally made the discovery when running on fuel cells. They constructed it with the use of an activated charcoal as the electrode material where a thin insulator separates the electrodes. This is serving as a base to date for designing SCs. The company didn’t commercialize such discovery, yet the technology was licensed to NEC, which after that marketed in 1978 [22].

4.1.1 Activated carbon
This is considered as one of the treated carbon forms that is produced through a series of relatively simple and inexpensive activation processes. It is obtained by burning carbon materials without oxygen and then the burned material is chemically and physically treated. It is treated to obtain small, finite pores that increases the surface area provided for chemical reactions or absorption. Due to the fact that they are less costly and have high surface area compared with the other carbon based materials, the activated carbon was the major utilized electrode material in SCs [9, 11]. Activated carbon has the ability for storing specific capacitance in range of (50-150) Fg⁻¹ for organic electrolytes and (100-200) Fg⁻¹ for aqueous electrolytes and achieving capacitances of 225 and 160 Fg⁻¹, respectively, with KOH treated activated carbon in the aqueous electrolytes [23].

4.1.2 Carbon aerogels
Carbon aerogels have been formed with interspersed mesopores from continuous network related to the conductive carbon nano-particles. External adhesive binding agent doesn’t need to be applied via carbon aerogels, due to such continuous structures as well as their capability for chemically bonding to current collector. Also, carbon aerogels have low ESR compared to activated carbon as binder less electrode. The main interest area in SC studies including carbon aerogels was such reduced ESR, which yields greater strength [24].
4.1.3 Graphene
Recently, there was a significant focus on graphene. Also, it is specified as a 2D structure with a single atom thick layer, emerging as a distinctive carbon material that is utilized for energy-storage devices since it is absorbing wide surface area, high electrical conductivity, and chemical stability characterizes [25]. It was recently suggested that graphene might be utilized as one of the substrates for the applications of SC, due to the fact when utilizing graphene as SC electrode materials, in contrary to the other carbon materials including carbon nanotube, activated carbon and so on; it isn’t based on the pores’ distribution at solid state [26]. Newly-formed graphene has high specific surface area of approximately 2630 m$^2$/g from all the carbon materials utilized as EDLCs for electrode materials [27]. Graphene has the ability of producing 550 F g$^{-1}$ capacitances in the case when totally exploiting the whole precise surface area [25]. Another advantage of utilizing graphene as one of the electrode materials was that graphene’s main surfaces were external and electrolyte-friendly. Researches are conducted on developing many forms of graphene, which include micro-mechanical exfoliation, arc discharge, chemical vapor deposition, electrochemical and chemical methods, and graphite intercalation methods [28].

4.1.4 Carbon nanotubes (CNT)
There was a major development in the engineering and the science related to carbon materials with the discovery of CNTs. The total resistance of the components is the element that defines the power density in a supercapacitor. Because of its distinctive pore structures, strong thermal and mechanical stability as well as the excellent electrical characteristics, a lot of focus was steered towards CNTs as SC electrode materials. Different from the other carbon based electrodes, CNTs have interconnected mesopores, which allows continuous distributions regarding the charge which applies the majority of accessible surface region. CNTs might be graded as single walled CNTs or multi walled CNTs, all of them were examined as materials for SC electrodes [29, 30]. CNT materials were indicated as high power electrode materials as a result of their simply accessible surface area as well as their high electrical conductivity. In the case of the high-power electrode materials carbon nanotube were regarded. In general, the surface area of the carbon nanotube is small (<500 m$^2$/g), that is contributing to low-energy density in comparison with the activated carbon. In order to increase its basic capacitance, the carbon nanotube might be activated (chemically) by means of KOH. The above method will significantly result in an increase in carbon nanotube surface area (by a factor of 2-3 times) and still retain its nano-tubular morphology [31].

4.2 Pseudocapacitor electrode materials
Commonly, the electrically conductive polymers and transition metal oxides are chosen as pseudocapacitor electrode materials. Also, the pseudo-capacitor electrodes are using redox reactions on the electro active materials’ surfaces. While the redox reactions were dependent on the electrode potential and changing according to the discharging and charging. This process is providing excellent energy density and capacitance in comparison to the purely carbon based EDLCs. Yet, such significant characteristics were typically counter-balanced with bad life-cycles. For instance, the EDLCs might be achieving up to 500,000 cycles, while the pseudo-capacitors have been compromised with the issues of cycling. This is due to the fact that multiple cycles related to the chemical reactions might be damaging the pseudo-capacitive materials along with inducing unwanted morphology changes, resulting in a performance decrease with the progress of cycling. In response, carbon supports were frequently added for resolving the detriment [32].

4.2.1 Metal oxides
Co3O4, NiO, RuO2, MnO2 and V2O5 are the major transition metal oxides presently studied for pseudo-capacitors electrodes. An increase in capacitance is caused when such metal oxides are undergoing multiple oxidation states at specific potentials. Ruthenium oxide (RuO2) In crystalline and amorphous forms, RuO2 is of high importance for practical and theoretical purposes, as a result of
its various properties, like the metallic conductivity, catalytic activities, high thermal and chemical stability, electro-chemical reduction oxidation characteristics and field-emitting behavior. Due to such characteristics, RuO2 is utilized in many applications including, thin or thick resisters, electronic applications, integrated circuit development and ferroelectric films. The latest RuO2 application is the electrode materials in SCs [9]. From the various metal oxides utilized as electrode materials, RuO2 was widely effective due to its benefits of long-life cycle, extremely reversible reduction oxidation reaction, wide potential window regarding the highly specific capacitance, along with their metallic type conductivity. With regard to SC applications, the RuO2 has been produced (electrochemically) by means of electro deposition approach. Furthermore, the subsequent electrodes have been stable for large number of cycles showing a 498 Fg⁻¹ as specific capacitance at 5mV/s scan rate [33]. Manganese Oxide (MnO2) a lot of researches are focusing on MnO2 due to its distinctive chemical and physical characteristics with a lot of applications in the catalysis, ion exchange, energy storage, biosensor and molecular adsorption. Also, it was highly significant as an electrode material for SCs because of its low-costs, good capacitive performances in the aqueous electrolytes as well as being environmentally-friendly [9, 11] Nickel oxide (NiO) are considerable electrode materials for SCs because of their low-costs, simply synthesis and being environmentally-friendly. Some of the electrochemical strategy advantages are simplicity, reliability, low-costs, versatility and accuracy. With the use of electrochemical strategy, the NiOH2 has been transformed into NiO. The subsequent approach generated ultra-high specific capacitance of 1478F/g in 1M of the KOH aqueous solution electrolyte [9].

4.2.2 Conducting Polymer (CPs)
CPs have been majorly examined as pseudo-capacitor materials, in which the charges were stored within reversible and fast redox reactions at the surface as well as the bulk related to electrode. In addition, the CP electrode materials, like the polypyrrole (PPy), polyaniline (PANi) and polyethylene dioxy thiophene (PEDOT), are showing maximal theoretical specific capacitance of 1000F/g (100μF/cm²-400μF/cm²), that has been approximately two-times high compared to that related to EDLCs. Generally, the CP good conductivity is due to the electrons’ delocalization along the backbone of the conjugated polymer, which allows the electron transport in doped state [34]. The CP’s intrinsic conductivity might be modified from their chemical structure with the use of economical approaches, in comparison to TMO. Also, CPs might be synthesized via chemical polymerization or electro-polymerizing the corresponding monomers. In spite of CP’s advantages, including higher electrical conductivity, low costs and excellent charge density, such material’s structural destruction (shrinking/swelling) throughout the process of charging/discharging might be considerably interrupting the rate capability performance and cycling stability of SCs [35,36]. Thus, the inclusion regarding carbon materials, for instance, graphene, porous carbon, CNTs, CNFs and graphene oxide was suggested as an excellent approach for maintaining CP electrochemical stability [37]. Taking into account the many conducting polymer types, PANI was specified as the major SC electrode material as a result of its simple synthesis, high-conductivity, low-costs and good capacity for energy storage. Yet, because of repetitive cycles (the process of charge/discharge) swelling and shrinkage, PANI has high susceptibility to fast performance degradation. For avoiding such drawback, combining carbon materials with PANI reinforced PANI’s stability and maximized the capacitance value [9].

4.3 Hybrid supercapacitors electrode Materials
Materials have been utilized in hybrid-type SCs. The composite materials consist of combinations regarding conducting polymers or metal oxides with carbon materials; thus, incorporate the aspects related to pseudo-capacitor and EDLC materials that are offering chemical and physical charge storage process together in one electrode [38].
5. Electrolytes
There is a conduction source in all devices. For instance, there is a dielectric in the conventional capacitors. Comparably, SCs are containing an electrolyte which was utilized for movement or conduction of ions. In addition, the significant parameters to select the electrolytes were the type and size of ions, concentration, and electrode materials, also the solvent and ion interaction. Power density, cycle life and capacitance might be affected via electrolytes. There is a necessity that the size of electrolyte’s ions must be less than or equal to the pore size related to electrode material. For instance, in the case when NaOH was the material utilized electrolyte and carbon, then the carbon’s pore size must be more compared to the size of electrolyte’s ion that is going to lead to high capacitance as well as power density [39, 40]. Figure 6 depicts important supercapacitor properties that are strongly influenced by electrolytes properties [41].

![Image of Electrolyte and Supercapacitor](image_url)

Figure 6. Supercapacitor Performance depends on Electrolyte properties[41].

5.1 Organic and Aqueous Electrolytes
The resistance of aqueous electrolytes is large compared to organic electrolytes; therefore, the latter have extremely low power capacity. Because of their small radius between ions and high-conductivity, the aqueous electrolytes are providing large capacitance compared to organic electrolytes [41]. The high-conductivity related to aqueous electrolytes was desirable to reduce Equivalent Series Resistance (ESR) that offers high-power density SCs. Phosphoric acids, sulfuric acids and KOH are the major utilized aqueous electrolytes. Propylene carbonate and Acetonitrile (ACN) were the major 2 solvents utilized in organic electrolytes. ACN has the ability of liquefying large salt portions, yet it is considered to be, whereas the propylene carbonate electrolytes have huge temperature, voltage and fairly adequate conductivity [17]. ACN has the ability for dissolving large salt amounts compared to other solvents, yet suffering from toxic and environmental issues. Furthermore, the propylene carbonate based electrolytes were environmentally-friendly and offering wide electrochemical window, excellent conductivity and various operating temperatures. Yet, one of the issues that must be considered is that the water content in the organic electrolytes should be kept not more than 3ppm – 5ppm, or else, an electrochemical SC voltage is going to be reduced considerably. Large voltage window is produced by organic electrolytes produce in comparison to aqueous electrolytes. Neutral, acid and alkaline solutions are the three categories of aqueous electrolytes [17, 40].
5.1.1 Acid Electrolyte
A lot of acids were utilized as electrolytes, and sulfuric acid was more commonly utilized in SCs. The movement or (conductivity) was on the basis of concentration. The electrolyte's ionic conductivity might be reduced rapidly in the case when the concentration was sharply increased or decreased. Also, the combination regarding 2 distinctive electrodes in various working potentials might be increasing the functioning potential window in aqueous electrolyte [17].

5.1.2 Alkaline Electrolyte
Alkaline electrolytes are vital alternative since the acid electrolytes weren’t adequate for all metal materials. KOH is the major alkaline aqueous electrolyte as it is providing excellent ionic conductivity [17,14].

5.1.3 Neutral Electrolyte
The less corrosive features and large working potential are the major significant characteristics of neutral electrolytes. Many neutral electrolyte types were utilized in SC researches, such as Na2SO4, LiCl, KCl, NaCl, and K2SO4. The major neutral electrolyte utilized in electrochemical reactions is Na2SO4, whereas the major pseudo-capacitive material and majorly examined in neutral electrolytes is MnO2. Also, the neutral electrolytes were used in terms of asymmetric SC devices, offering wide potential window to achieve higher energy density. Along with solving the issues of electro-chemical SC corrosion, the neutral aqueous electrolytes are offering inexpensive and environmentally-friendly alternatives for enhancing the performance related to electrochemical SCs, with large energy density and operating voltage, even with the existence of difficulties to achieve enhanced cycle stability [17].

5.2 Ionic Liquids
SCs are majorly focusing on Room Temperature Ionic Liquids (RTILs) due to the fact that they are poorly combustible, heat resistance and non-volatile, with such characteristics being extremely impracticable and rare with the traditional solvents. With regard to RTILs, minimum of single ion typically has delocalized charge as well as one component is organic, that is preventing the formation regarding stable crystal lattice. In addition, some characteristics like conductivity, viscosity and melting point were controlled via the two substituents on organic ion. A lot of ionic liquids might and were created with large variations of the physicochemical properties. Therefore, the ionic liquids were referred to as designer solvents [42].

6. Separators
Not much study is provided to develop well engineered separation even with the various developments in enhancing SC electrodes. The separators might be badly impacting the SC performance due to the fact that badly-designed separators might be inducing more cells' resistances. In worst case scenario, this might short circuit the cell. Many points are considered when choosing suitable separators for SCs, such as:

- Non-conductive (electron transport is prevented between electrodes)
- Chemical resistance to the electrode materials and electrolytes
- Electrolyte ion permeable with the minimal ionic resistance
- Simply wetted via electrolytes
- Mechanical resistance to the variations in the volume and pressure, such as the swelling

The natural materials, including ceramics, glass and cellulose paper have been utilized initially as separators in initial stages that are related to SC development. However, evolutions of polymer-based separator types were dominating the separator market due to their low-costs, excellent flexibility, as well as high porosity. Furthermore, the polymer separators might be divided into 2 classes, which are: fibrous structure and monolithic network with the defined pores [17].
7. Recent developments in the supercapacitor industry
In the last ten years, researchers have been interested in improving the mechanism of storing the charge in super-capacitors, so they have done different experiments using various electrode materials and electrolytes. Most of them have turned to hybrid capacitors because they provide a unique storage mechanism because the electrode materials in them are composite and able to provide a storage mechanism for their shipment Physical and chemical together. Carbon-based materials are integrated by composite electrodes with conducting polymer materials or metal oxides.

7.1 Binary composites

7.1.1 Carbon-Carbon composites
Chen, Yao, et al. (2012) [43] With regard to carbon materials, high capacitance was acquired on the basis of effective specific surface area (SSA) that was available for the electrolyte ions. In carbon materials, improving the SSA is going to result in high energy as well as power density in SCs. Also, graphene is facing a dispersion problem; thus, non-covalent functionalized was prepared for coming up with solutions. A drawback of utilizing chemical reduction related to graphene oxide was that it has a tendency for aggregating and restacking via the interactions of van der Waals throughout the process of reduction; thus, the surface area becomes less accessible to an electrolyte. Zhang et al. (2013) [44] for avoiding restacking, SWCNTs are used as spacers. When CNTs are inserted intra pores for the electrolyte will be created. A 123Wh/kg energy density and a 261F/g capacitance have been acquired for SCs at potential 3.7V by means of ionic liquid electrolyte. Zheng, Chao, et al. (2014) [45] an approach was created for preparing graphene/(AC nano-sheet composite as electrode materials of high performance for the SC. With regard to such composite, a porous AC layer coats on graphene for creating wrinkled nano-sheet structure, with thickness of tens of nanometer and length of a few micrometers. In addition, the composite has fairly large SSA of 2106m2 g−1 and high packing density of approximately 0.3g/cm3, also contains some mesopores. It is showing specific capacitance of 103F/g in organic electrolyte and 210F/g in aqueous electrolyte, also the there is a decrease in the specific capacitance by just 5.30% following 5,000 cycles. The results are indicated that porous graphene/AC nano-sheet composite are prepared via hydro-thermal carbonization and chemical activation might be implemented for the high-performance SCs.

7.1.2 Carbon-Metal Oxides Composites
Choi, Changsoon, et al [46] (2016) Highly-performing and reversibly deformable solid state yarn SCs were acquired with the use of MnO2 deposited micro-coiled yarn electrodes. Also, the core (CNT) shell (MnO2)-structured coiled electrodes are achieving high level of the stretch ability of (37.5%) with no help of the elastomeric substrates, reducing the SCs size. Thus, high specific capacitances of 61.25 mF cm−2, 34.6F/cm3 and 2.72mF/cm were reached for coiled SCs with no impairment of mechanical stretch ability. Ochah-Ejeh, Faith, et al. (2018) [47] The researches designed a hybrid capacitor device which consists of 3D nano-structured activated carbons as negative electrode materials, since such material has high-conductivity along with the delicate structural characteristics. With regard to positive electrode materials, MnO2-CNT nano-composite has been prepared via fabricating the MnO2 from the surface of CNTs through the surface water thermal reflux approach. In addition, these electrode materials are showing excellent electrochemical performance. Furthermore, a hybrid device that has a ~25Wh/Kg energy density that corresponds to a 500W/Kg power density at 0.50A/g current density. The stability related to ~100% coulombic efficiency following 10000 charge discharge cycles and sufficient retention of the capacitance following potentio-static floating test for 60h. Cheng, Qian, et al. (2011) [48] an asymmetric SC has been assembled with the use of MnO2 and graphene. Also, the prepared composite related to MnO2-coated/graphene was utilized as cathode, whereas the pure graphene has been utilized as anode. In addition, the electro activation process was utilized on the graphene electrode, also a 245F/g capacitance at 1 mA charging current is obtained. In the case when MnO2 has been deposited, there will be an increase of capacitance to 328F/g at the same charging current, 25.8kW/kg of the power density and 11.40Wh/kg
of energy density were acquired. Bi, Rong-Rong, et al. (2010) [49] RuO2/CNT nano-composites with well dispersed NPs of the RuO2 (diameter less than 2nm) on CNT surface, also synthesized via effective and simple solution based approach, were examined for possible applications in electrochemical capacitors (EC) as electrode materials. In addition, the electro-chemical results are showing that CNT’s supporting material might be considerably promoting the RuO2 super-capacitance performance. Furthermore, the RuO2 NPs in composite with RuO2/CNT 6:7 mass ratio might be achieving a specific capacitance of 953F g$^{-1}$. In addition to that, the results are showing that the resultant RuO2/CNT nano-composites were excellent electrode materials for the high specific capacitance ECs as well as considerably improved high energy and high power capabilities and enhanced cycling performance in comparison to bare RuO2. At 5000 W kg$^{-1}$ power density, the RuO2/CNT composite (RuO2/CNT = 6:7 in wt %) might be still delivering 16.8 Wh kg$^{-1}$ as energy density, that is approximately 5.8-times large compared to bare RuO2 (2.90Wh kg$^{-1}$). Whereas, the much-improved electro-chemical performances might be due to the dispersive action and excellent electronic conductivities of the CNT and the pinning impact for nano-sized RuO2 particles on the surface of CNT. Zhang, Xiong, et al. (2012) [50] suggested a design SCs on the basis of AC as a negative electrode as well as MnO2/activated carbon (MnO2/AC) nano-composite as a positive electrode. The device is delivering 50.6F/g specific capacitance and 28.1 Wh/kg as energy density. Wen et al. [51] (2017) MnO2 (20–50 nm) have been electro-deposited on activated carbon fiber sheets (CFS), offering high specific capacitance of 375F/g at 1A/g, a significant specific energy (11.0Wh/kg at 529 W/kg as specific power), also an excellent long term cycle stability (capacitance of 99.20% retained following 5,000-cycles). Also, the excellent electro-chemical performance regarding the acquired CFSs/MnO2 might be due to the synergistic faradic effects as well as EDLC charge storage process and large electro-active sites offering rapid diffusion and migration of the ion of the electrolyte. Śliwak and Gryglewicz [52] (2014) indicated high voltage asymmetric supercapacitors (ASCs) on the basis of AC as a negative electrode as well as manganese oxide/oxidized carbon nanofibers (MnO2/CNFox) as a positive electrode. Also, MnO2/CNFox/AC ASCs indicated a wide potential window of 0V–2.40V, 24.8 Wh/kg as maximum specific energy at 100 W/kg as specific power and excellent stability performance of (92.4%) following cycling for 5000-times.

7.1.3 Carbon- Conducting Polymer Composites

Yan, Jun, et al. (2010) [53] High SSA (1,976 m$^2$/g), narrow pore size distribution (less than 3.0nm) and short length of diffusion have been acquired in the case where activated-carbon has been synthesized from PANI carbonization and after that activated with KOH. The subsequent composite showed good efficiencies. In addition, a high specific capacitance of 455F/g in KOH of 6M has been acquired. Furthermore, graphene is added to PANI and following 2,000-cycles, there has been an increment in the specific capacitance retention ration from 88.70% to 94.60%. Yan, Jun, et al. (2010) [54] carried out involving a composite of GNS/PANI. The composite is synthesized with the use of in-situ polymerization, because of the existence regarding GNS in the composite offered high-conductivity and fairly large area, in which the particles of PANI have been deposited. Also, high specific capacitance of 1046 F/g at 1mV/s is acquired with 39Wh/kg as energy density and 70kW/kg of power density. Qu, Guoxing, et al. (2016) [55] Hollow graphene/conducting polymer composite fiber was developed with high electronic and mechanical characteristics and utilized for fabricating new fiber shaped SCs displaying long-life stability and high energy densities. Furthermore, the fiber SCs might be woven into simple powering textiles which were especially significant for wearable and portable electronic devices. Salinas-Torres, David, et al. (2013) [56] Chemical and electrochemical approaches were utilized for preparing composites which includes PANI coatings within activated carbon fiber (ACF) micro porosity. In addition, the electrochemical characterization regarding the two composites is showing that PANI electrodes have high capacitance compared to porous carbon electrode. In addition, materials were utilized for building asymmetric capacitor on the basis of AC as a negative electrode as well as ACF–PANI composite as a positive electrode in the H2SO4 solution as electrolyte. Furthermore, inside the ACF’s porosity, the existence regarding PANI thin layer is preventing the oxidation related to the carbon content as well as the reaction of oxygen evolution was
created at more positive potential. The capacitor is put to test in 1.6 V as maximum cell voltage and showed high energy densities, evaluated for un-packaged active materials, with 20W h kg⁻¹ values and 2.10 kW kg⁻¹ of power densities with good cycle lifetime (90% throughout the first 1,000-cycles) as well as high columbic efficiency. Li, Jianpeng, et al. (2020) [57] they synthesized PANI that is grafted with CF composite (PANI-g-CF). Also, PANI-g-CF is showing exhibits highly electronic conductivity as well as advantages from fast charge transfer for charges’ storage. Also, PANI-g-CF is showing specific capacitance of 441 F g⁻¹ at 1 A g⁻¹ as a SC electrode material with a 75.43% as rate capability between (1A g⁻¹ - 10 A g⁻¹). Particularly, PANI in the PANI-g-CF has high specific capacitance of 1178 F g⁻¹, specifying an ultra-use regarding PANI for SC. In addition, the assembled flexible SCs with PANI-g-CF as electrode materials are showing high stability in long term periods with 88.8% and 92.90% of initial capacitance following 10000-cycles and mechanical folding-2000 times, respectively because of the ultra-intimate contact regarding CF and PANI.

7.2 Ternary Composites
Kshetri, Tolendra, et al. (2020) [58] the researchers developed hybrid SC with negative electrode CNT@Gr-CNFe as well as positive electrode nano-needle which is grown on a nickel foam (NiCo2S4/Ni). The negative electrode (CNTs@Gr-CNFe) was developed via integrating CNFs, graphene and CNTs. Also, the device is showing a 218 F g⁻¹ capacitance at 1 A g⁻¹ and 94.98% retention following 10,000-cycles. In addition, the device is showing 62.13Wh kg⁻¹ of energy density at power of 789.66W kg⁻¹. Furthermore, the acquired results are signifying that the carbon materials with hierarchical nano-structures were well-accepted propitious materials for electrode application in super capacitor devices. Xiong, Shanshan, et al. (2020) [59] The researchers proposed designing a hybrid capacitor which consists of CNTs as negative electrode as for positive electrode, they designed a new strategy to synthesize well aligned porous NiO@Ni-MOF/NF cylindrical cage shape structure obtained from NiO self-sacrificed template and precursor. Since such distinctive composition improves the conductivity related to electrode, also, it is working on transferring the electrons and ions in storing electrochemical energy. The (MOF)Metal-organic framework. It is a class of porous materials that have been widely used in supercapacitors, but their use poses a great challenge due to poor conductivity and internal instability. This hybrid capacitor exhibits a specific capacitance of 144 F g⁻¹ at 1 A g⁻¹. The maximum energy and power densities of this device reach to 39.2 Wh kg⁻¹ and 7000 W kg⁻¹, respectively, showing good cycling stability with 94% capacity retention over 3,000 cycles. Zhu, Yulu, et al. (2020) [60] Hybrid capacitor was manufactured the AC as the negative electrode and the positive electrode material NiCoP@C@LDHs. Herein, battery-type NiCoP@C@LDHs electrode with a hierarchical structure of the core-shell, which NiCoP@C nano-wires array is taken for core, for the purpose of supporting NiCo-based nano-sheets shell was assembled successfully. The nano-wires NiCoP@C core, acting like highly solid and conductive skeleton, results in the acceleration of the electron transfer besides the prevention of the nano-sheets’ agglomeration. Hybrid super-capacitor accomplished a high energy density 48.30Wh kg⁻¹ at a 800W kg⁻¹ power density. This device showed capacitance retention of approximately 160% more than 10,000 cycles. Ji, Zhenyuan, et al. (2020) [61] They suggest to design a hybrid capacitor consisting of a by flower-like CoS/N-dopd CDs negative electrode and rGO/N-dopd CDs positive electrode achieves an energy density 36.60Wh kg⁻¹ at 800W kg⁻¹ and electrochemical stability with 85.90% retention following 10,000 cycles at 10A/g. This research presents a new insight for coordinate designing cathodes and anodes or high-performance for the development of new types of the hybrid super-capacitors.

8. Conclusions
This paper offered a simple overview of supercapacitors as well as a rundown of recent developments. It was discussed how these supercapacitor architectures can be classified into three different groups based on how they store charge and then classified based on electrode material used. Electrochemical double-layer capacitors (EDLC), pseudo-capacitors, and hybrid capacitors are the three types. Supercapacitors (SCs) have the ability for storing potential energy as electric charge, and capacitance values changing from the Pico-farad to the microfarad. SCs were graded in farads that are considered as 1000-times that related to electrolytic capacitor. Also, the SC’s energy density was more compared
to that of capacitor, yet not more than the battery, yet, due to their flexibility, SCs might be adapted for serving in certain roles for which the electrochemical batteries weren’t well-suited. SCs have a few intrinsic properties which is making them suitable to specialized roles as well as applications complementing the batteries’ strengths. Particularly, SCs have considerable potential for the applications requiring a combination of short charging time, high-power, long shelf life and high cycling stability. Various electrode materials were utilized for studying the behavior and enhancing the SC’s performance. Now researchers are focused on ternary composite which has been reported.

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