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Ultra Capacitor: An Overview And Its Role As Conditioner In Power System

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ABSTRACT

To meet enormous load requirements, power industry is harvesting Distributed Energy Resources (DERs). The impact of DERs is on distribution grid is not unavoidable i.e. power quality issues and intermittencies. To mitigate power quality problems and intermittencies Ultra capacitor integrated with power conditioner is presented in this paper. In the first section review of ultra-capacitor is presented.

Keywords

DERs, Ultra capacitor, Power conditioners

1. INTRODUCTION

If said vividly today's society is completely power dependent that is the complete system collapses as the power goes off. Traditionally power industries have been exploiting fossil fuels for generating electrical power at the large. Due to enormous burning of these fuels they are depleting day by day so it is an urgent need of time to develop some renewable and sustainable means to generate electricity such as solar, wind etc. The principal drawback of these systems is interruption or discontinuity in power generation and intermittencies on distribution side. Similarly it is rather difficult to integrate these power generating units in generation pool as compared to centralized plants as they are operator controlled. The prominent energy storage systems can solve above difficulties. So in addition to sustainable energy sources, certain efficient energy storage systems are critically needed. [1] Most importantly, it is experienced that due to penetration of distributed energy sources (DERs) like solar, wind, and plug-in hybrid electric vehicle (PHEVs) power quality problems are rising their heads in distribution grids. So, again power engineers have been working on various power quality conditioners such as dynamic voltage restorer (DVR) and active power filter (APF). The function of different power conditioners are different under different conditions. DVR works to mitigate voltage sags and voltage swells, whereas APF prevents the grid from supplying non-sinusoidal currents when the load is nonlinear. When both of these conditioners are integrated it is called unified power conditioner (UPQC). But this is limited to distribution grid voltage sag, swells and some harmonic problems only. [2]

For mitigating not only the power quality problems but the intermittencies an optimal integration of Energy Storage Systems with Distributed Energy Resources DERs is the best solution. In this technique reliability of the power grid is improved to greater extent and the quality problems are also resolved. [10,11] In literature a good many approaches are found where an efficient energy storage systems are used to solve certain quality problems and intermittencies. In this paper an overview of an Ultra capacitor and its role as power conditioner is elaborated. Deepak Somayajula, and Mariesa L. Crow proposes the concept of integrating UCAP-based rechargeable energy storage to a power conditioner system to improve the power quality of the distribution grid [2].J. G. Nielsen, M. Newman, H. Nielsen, and F. Blaabjerg proposes control and testing of a dynamic voltage restorer (DVR) at medium voltage level. [3]. V. Soares, P. Verdelho, and G. D. Marques proposes an instantaneous active and reactive current component method for active filters. A shunt active filter based on the instantaneous active and reactive current component - method is proposed. [4]. H. Akagi, E. H. Watanabe, and M. Aredes, proposes Instantaneous Reactive Power Theory and Applications to Power Conditioning. [5]. K. Sahay and B. Dwivedi proposes Super capacitors energy storage system for power quality improvement. [6] B. M. Han and B. Bae proposes Unified power quality conditioner with super-capacitor for energy storage. This paper proposes a new configuration of UPQC (Unified Power Quality Conditioner) that consists of the DC/DC converter and the super capacitors for compensating the voltage interruption. [7] P. F. Ribeiro, B. K. Johnson, M. L. Crow, A. Arsoy, and Y. Liu proposes Energy storage systems for advanced power applications. [8] A. B. Arsoy, Y. Liu, P. F. Ribeiro, and F. Wang proposesStatCom. SMES superconducting magnetic energy storage (SMES) systems for power utility applications have received considerable attention due to their characteristics, such as rapid response (milliseconds), high power (multimegawatts), high efficiency, and four quadrant control. SMES systems can provide improved system reliability, dynamic stability, enhanced power quality, and area protection. [9]

2. AN ULTRA-CAPACITOR

Ultra capacitors are advanced capacitors, these are also known as super capacitors and are electrochemical double layer capacitors (EDLC). In ultra-capacitors energy storage capacity is increased by increasing surface area through use of a porous electrolyte as shown in figure below (they have relatively low permittivity and voltage-withstand capabilities). Several different combinations of electrode and electrolyte materials have been used in ultra-capacitors, with different combinations resulting in varying capacitance, energy density, cycle-life, and cost characteristics. At present, ultra-capacitors are most applicable for high peak-power, low-energy situations.The main features of ultra-capacitors are; it is capable of floating at full charge for ten years, can provide extended power availability during voltage sags and momentary interruptions, can be stored completely discharged, installed easily, compact in size, and can operate effectively in diverse (hot, cold, and moist) environments. Ultra capacitors are now available commercially at lower power levels [12].

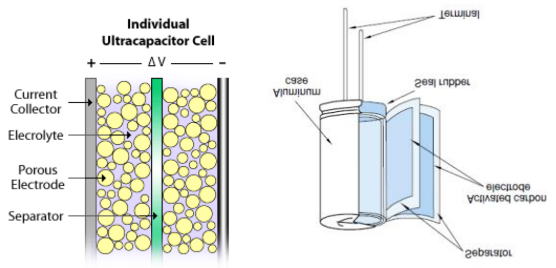
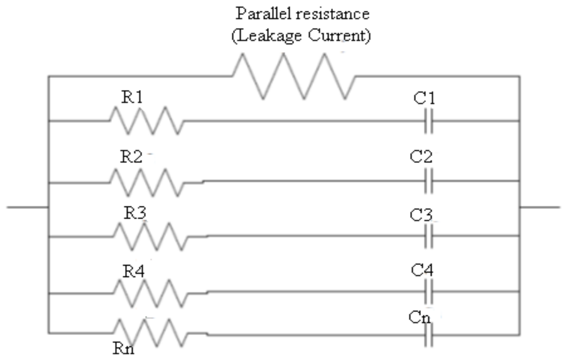


Figure 1. Individual capacitor cell

The surface area of the activated carbon layer is extremely large yielding several thousands of square meters per gram. This large surface area allows for the absorption of a large amount of ions. The charging/discharging occurs in an ion absorption layer formed on the electrodes of activated carbon. The activated carbon fiber electrodes are impregnated with an electrolyte where positive and negative charges are formed between the electrodes and the impregnate. The electric double layer formed becomes an insulator until a large enough voltage is applied and current begins to flow. The magnitude of voltage where charges begin to flow is where the electrolyte begins to break down. This is called the decomposition voltage. The double layers formed on the activated carbon surfaces can be illustrated as series of parallel RC circuits. As shown below the capacitor is made up of a series of RC circuits where R1, R2 …Rn are the internal resistances and C1, C2..., Cn are the electrostatic capacitances of the activated carbons. When voltage is applied current flows through each of the RC circuits. The amount of time required to charge the capacitor is dependent on the CxR values of each RC circuit. Obviously the larger the CxR the longer it will take to charge the capacitor.



2.1. Features of Ultra capacitors

Attractive features of UCAP are its high capacitance, short duration peak power delivery capacity i.e. high power density, reduced space, environmentally safe, low power to weight ratio and very long cycle life.

Table.1 Specifications:

Capacitance	1700 F
Continuous operation voltage	2.7V
Peak operation voltage	2.85V
Current rating	360A

2.2. Applications

In recent era as described in introduction, ultra-capacitors are used in hybrid storage systems combined with cell fuel or SMES because these systems are complementary. A typical super capacitor application is its use as a storage system in electric or hybrid vehicles, improving their performance, efficiency and economic viability. Due to advances in technology and the increase in the energy storage capacity, these Systems are beginning to be considered for energy storage systems in renewable energy generation plants. Other scenarios where the use of super capacitor based systems are beginning to be researched are: active power filters; power quality improvement of distribution and transport systems; locomotives; for battery substitution in electronic devices (due to their large useful life) ; intermediate energy storage systems [108]; and in whatever medium level power application that requires an energy storage of high response times, low installation and maintenance costs, and small energy storage capacity.

3. ULTRA CAPACITOR AS POWER CONDITIONER

To meet the power demand power industry has been seeking substantial and eco-friendly sources of energy.

That's the Distributed Energy resources like wind, solar etc. But with the increase in penetration of the distributed energy resources (DERs) like wind, solar, and plug-in hybrid electric vehicles (PHEVs), one should not ignore the impacts of DERs. That is a corresponding increase in the power quality problems and intermittencies on the distribution grid in the seconds to minute's time scale. Energy storage integration with DERs is a potential solution, which will increase the reliability of the DERs by reducing the intermittencies and also aid in tackling some of the power quality problems on the distribution grid.

Of all the rechargeable energy storage technologies superconducting magnet energy storage (SMES), flywheel energy storage system (FESS), battery energy storage system (BESS), and ultra-capacitors (UCAPs), UCAPs are ideal for providing active power support for events on the distribution grid which requires active power support in the seconds to minutes time scale like voltage sags/swells, active/reactive power support, and renewable intermittency smoothing.

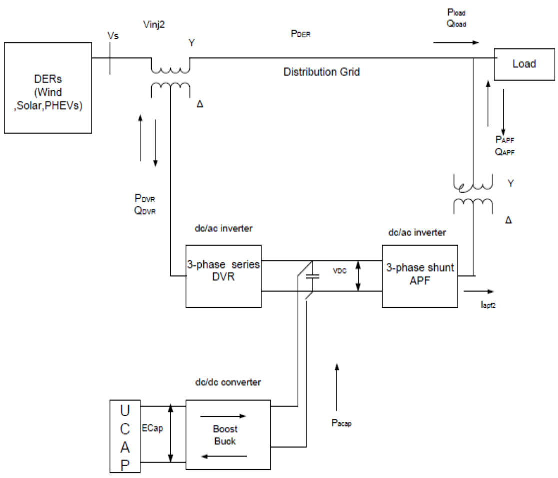


Figure 2. Block diagram of the Power Conditioner with UCAP Energy Storage

3.1. Power Stage

The power stage consists of two back-to-back three-phase voltage source inverters connected through a dc-link capacitor. UCAP energy storage is connected to the dc-link capacitor through a bidirectional dc–dc converter. The series inverter is responsible for compensating the voltage sags and swells; and the shunt inverter is responsible for active/reactive power support and renewable intermittency smoothing.

The complete circuit diagram of the series DVR, shunt APF, and the bidirectional dc–dc converter is shown in figure below. UCAPs can deliver very high power in a short time span; they have higher power density and lower energy density when compared with Li-ion batteries. The major advantage UCAPs have over batteries is their power density characteristics, high number of charge–discharge cycles over their lifetime, and higher terminal voltage per module. These are ideal characteristics for providing active/reactive power support and intermittency smoothing to the distribution grid on a short-term basis.

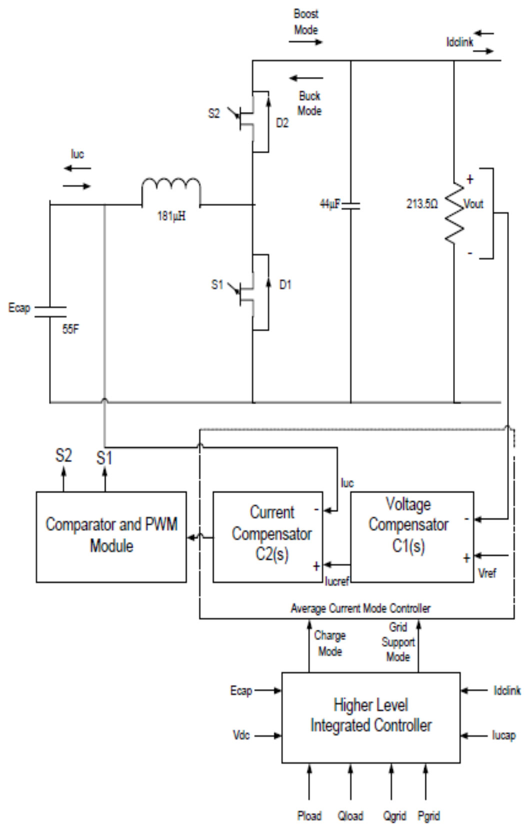


Figure 3.Model of the bi-directional dc-dc converter and its controller

Average current mode controller and the higher level integrated controller are shown in Fig. 4(a), where the actual output voltage V_{out} is compared with the reference voltage V_{ref} and the error is passed through the voltage compensator C1 (s), which generates the average reference current I_{ucref} . This is then compared with the actual UCAP current (which is also the inductor current) I_{uc}, and the error is then passed through the current compensator C2 (s). The converter model for average current mode control is based on the following transfer functions:

$$G_{id}(s) = \frac{V_{out}(sC+\frac{2}{R})}{s^2LC+\frac{sL}{R}+(1-D)^2}$$

$$G_{vi}(s) = \frac{(1-D)\left[1-\frac{sL}{R(1-D)^2}\right]}{(sC+\frac{2}{R})}$$

4. RESULT AND CONCLUSION

The simulation of the proposed UCAP integrated power conditioner system is carried out in MATLAB for a 208-V, 60-Hz system, where 208 V is 1 p.u. The system response for a three-phase voltage sag which lasts for 0.1 s and has a depth of 0.64 p.u.

a. It can be observed from Fig. 5(a) that during voltage sag, the source voltage Vsrms is reduced to 0.36 p.u., while the load voltage VLrms is maintained constant at around 1.01 p.u. due to voltages injected in-phase by the series inverter. Here source voltage Vsrms is indicated by green and VLrms is indicated by violet.

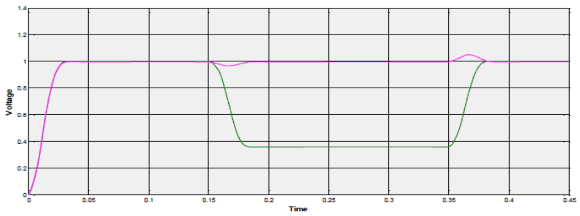


Figure.4.Source and load rms voltages during sag

b. This can be observed from the plots of the line–line source voltages (Vsab, Vsbc, and Vsca) [Fig. 5(b)] that source voltages are reduced due to voltages injected in phase by the series inverter. Here source voltages are indicated by Vsab (green), Vsbc (violet), and Vsca (blue).

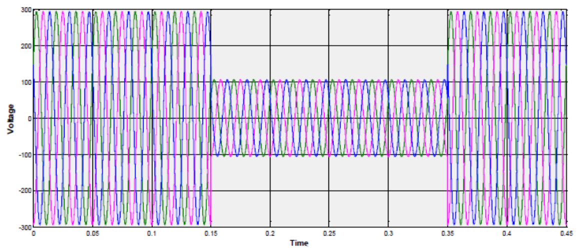


Figure.5. the plots of the line–line source voltages

c. This can also be observed from the plots of the line–line load voltages (VLab, VLbc, and VLca) [Fig. 5(c)] that load voltages are maintained constant during sag. Here load voltages are indicated by VLab (green), VLbc (violet), and VLca (blue)

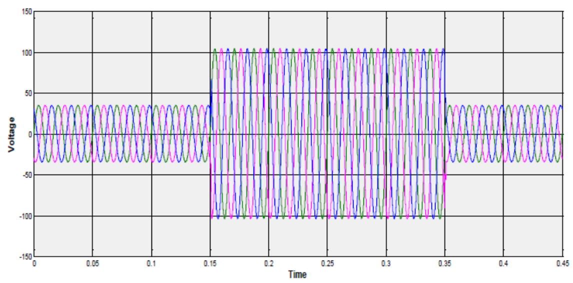


Figure.6 from the plots of the line–line load voltages

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