An Ultra capacitor Integrated Power Conditioner for Intermittency Smoothing and Improving Power Quality of Distribution Grid

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***Abstract*—Penetration of various types of distributed energy resources (DERs) like solar, wind, and plug-in hybrid electric vehicles (PHEVs) onto the distribution grid is on the rise. There is a corresponding increase in power quality problems and intermittencies on the distribution grid. In order to reduce the intermittencies and improve the power quality of the distribution grid, an ultra capacitor (UCAP) integrated power conditioner is proposed in this paper. UCAP integration gives the power conditioner active power capability, which is useful in tackling the grid intermittencies and in improving the voltage sag and swell compensation. UCAPs have low energy density, high-power density, and fast charge/discharge rates, which are all ideal characteristics for meeting high-power low-energy events like grid intermittencies, sags/swells. In this paper, UCAP is integrated into dc-link of the power conditioner through a bidirectional dc–dc converter that helps in providing a stiff dc-link voltage. The integration helps in providing active/reactive power support, intermittency smoothing, and sag/swell compensation. Design and control of both the dc ac inverters and the dc–dc converter are discussed. The simulation model of the overall system is developed and compared with the fuzzy logic controller system.**

1. INTRODUCTION

In the last few years the pollution problems and the increase of the cost of fossil energy (oil, gas) have become planetary problems. The car manufacturers started to react to the urban pollution problems in nineties by commercializing the electric vehicle. But the battery weight and cost problems were not solved. The batteries must provide energy and peaks power during the transient states. These conditions are severe for the batteries. To decrease these severe conditions, the super capacitors and batteries associate with a good power management present a promising solution.

Super capacitors are storage devices which enable to supply the peaks of power to hybrid vehicle during the transient states. During the steady states, batteries will provide the energy requested. This methodology enables to decrease the weight and increases the lifespan of the batteries. Hybridization using batteries and super capacitors for transport applications is needed when energy and power management are requested during the transient sates and steady states. The multi boost and multi full bridge converters will be investigated because of the high power. For range problems, traction batteries used until now cannot satisfy the energy needed for future vehicles. To ensure a good power management in hybrid vehicle, the multi boost and multi full bridge converters topologies and their control are developed. Two topologies proposed for the power management in ECCE Hybrid Vehicle are presented.

Most of the appliances today are powered by electricity and electrical power is transmitted over long distance stop over the appliances. During the initial days of commercialization and mass-production of electricity, Nikola Tesla proved to the world that electrical power can be transmitted over long distances in a much more efficient way if poly phase alternating current transmission is used instead of direct current transmission. Since then most of the electrical energy is transmitted over long distances using 3phase alternating current. One of the major draw backs of electrical energy in a current system is that it cannot be stored electrically.

II. POWER QUALITY

Power quality is a major cause of concern in the industry and it is important to maintain good power quality on the grid. Therefore, there is renewed interest in power quality products like the dynamic voltage restorer (DVR) and the active power filter (APF).The DVR prevent sensitive loads from experiencing voltage sags/swells and the active power filter (APF) prevents the grid from supplying non-sinusoidal currents when the load Is non-linear. The concept of integrating the dynamic voltage restorer (DVR) and active power filter (APF) through a back-back inverter topology was first introduced and the topology was called a unified power quality conditioner (UPQC).The design goal of the UPQC was to improve the power quality of the distribution grid by being able to provide sag, swell and harmonic current compensation. With the increase in penetration of the distributed energy resources (DERs) such as wind, solar and PHEVs, there is a corresponding increase in grid intermittencies and power quality problems on the distribution grid in the *seconds* to *minutes* time scale. Integration of energy storage in to the distribution grid is a potential solution which helps in addressing various power quality problems and problems related to grid intermittencies. Applications where energy storage integration is needed are being identified and efforts are being made to make energy storage integration commercially viable on a large scale.

Renewable intermittency smoothing is one application which requires active power support from energy storage in the *seconds* to *minutes* time scale. Different types of optimal controls are being explored to provide smoothing of DERs. In a super capacitor and flow battery hybrid energy storage system is integrated into the wind turbine generator to provide wind power smoothing and the system is tested using a real time simulator. In a super capacitor is used as auxiliary energy storage for PV/fuel cell and a model based controller is developed for providing optimal control. In battery energy storage system based control to mitigate wind/PV fluctuations is proposed. In a multi-objective optimization method to integrate battery storage for improving PV integration in to the distribution grid is proposed. In a rule based control is proposed to optimize the battery discharge while dispatching intermittent renewable resources.

In optimal sizing of zinc bromine based battery for reducing the intermittencies in wind power is proposed.

III.ULTRA CAPACITOR (OR) SUPER CAPACITORS

Capacitors store electric charge. Because the charge is stored physically, with no chemical or phase changes taking place, the process is highly reversible and the discharge-charge cycle can be repeated over and over again, virtually without limit. Electrochemical capacitors (ECs), variously referred to by manufacturers in promotional literature as Super capacitors also called ultra capacitors and electric double layer capacitors (EDLC) are capacitors with capacitance values greater than any other capacitor type available today. Capacitance values reaching up to 400 Farads in a single standard case size are available. Super capacitors have the highest capacitive density available today with densities so high that these capacitors can be used to applications normally reserved for batteries. Super capacitors are not as volumetrically efficient and are more expensive than batteries but they do have other advantages over batteries making the preferred choice in applications requiring a large amount of energy storage to be stored and delivered in bursts repeatedly.

The most significant advantage super capacitors have over batteries is their ability to be charged and discharged continuously without degrading like batteries do. This is why batteries and super capacitors are used in conjunction with each other. The super capacitors will supply power to the system when there are surges or energy bursts since super capacitors can be charged and discharged quickly while the batteries can supply the bulk energy since they can store and deliver larger amount energy over a longer slower period of time.

Controller Implementation:

$$\begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} \cos\left(\theta - \frac{\pi}{6}\right) & \sin\left(\theta - \frac{\pi}{6}\right) \\ -\sin\left(\theta - \frac{\pi}{6}\right) & \cos\left(\theta - \frac{\pi}{6}\right) \end{bmatrix} \begin{bmatrix} \frac{V_d}{\sqrt{3}} \\ \frac{V_q}{\sqrt{3}} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} V_{refa} \\ V_{refb} \\ V_{refc} \end{bmatrix} = m * \begin{bmatrix} \left(\sin\theta - \frac{V_{sa}}{169.7}\right) \\ \left(\sin\left(\theta - \frac{2\pi}{3}\right) - \frac{V_{sb}}{169.7}\right) \\ \left(\sin\left(\theta + \frac{2\pi}{3}\right) - \frac{V_{sc}}{169.7}\right) \end{bmatrix} \quad (2)$$

$$\begin{aligned} P_{dvr} &= 3V_{inj2a(rms)} I_{La(rms)} \cos\varphi \\ Q_{dvr} &= 3V_{inj2a(rms)} I_{La(rms)} \sin\varphi. \end{aligned} \quad (3)$$

$$P_{ref} = -\frac{3}{2} v_{sq} i_{qref}$$

$$Q_{ref} = -\frac{3}{2} v_{sq} i_{dref}$$

$$\begin{bmatrix} i_{refa} \\ i_{refb} \\ i_{refc} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_{dref} \\ i_{qref} \end{bmatrix}.$$

The series inverter controller implementation is based on the *in-phase compensation* method that requires PLL for
estimating θ, and this has been implemented using the *fictitious power method* described in [4]. Based on the estimated θ and the line–line source, voltages *Vab*, *Vbc*, *Vca* (which are available for this delta-sourced system) are transformed into the d–q domain and the line–neutral

components of the source voltage *Vsa*, *Vsb*, and *Vsc* which are not available can then be estimated using above equations. These voltages are normalized to unit sine waves using
line–neutral system voltage of 120 *V*rms as reference and compared with unit sine waves *in-phase* with actual system voltages *Vs* from (2) to find the injected voltage references *V*ref necessary to maintain a constant voltage at the load terminals, where *m* is the modulation index, which is 0.45 for this case. Therefore, whenever there is a voltage sag or swell on the source side, a corresponding voltage *V*inj2 is injected in-phase by the DVR and UCAP system to negate the effect and retain a constant voltage *VL* at the load end. The actual active and reactive power supplied by the series inverter can be computed using (3) from the rms values of injected voltage *V*inj2*a* and load current *ILa* and ϕ is the phase difference between the two waveforms.

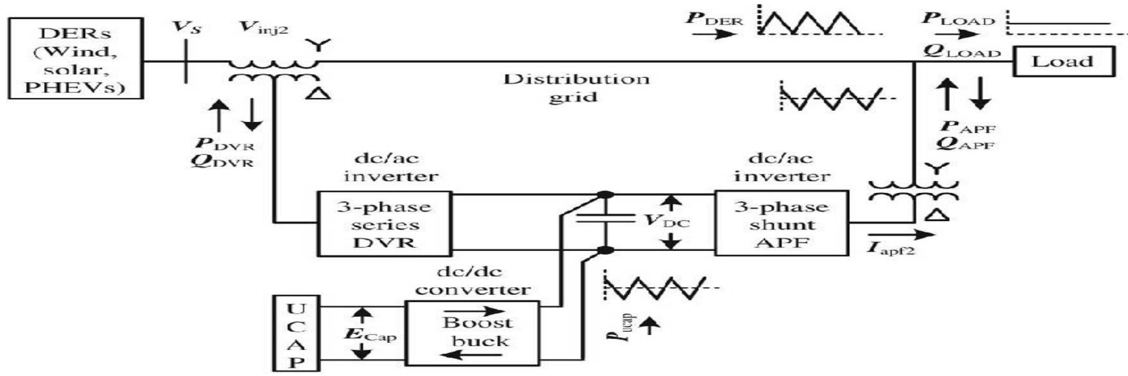

Fig. 1. One-line diagram of power conditioner with UCAP energy storage

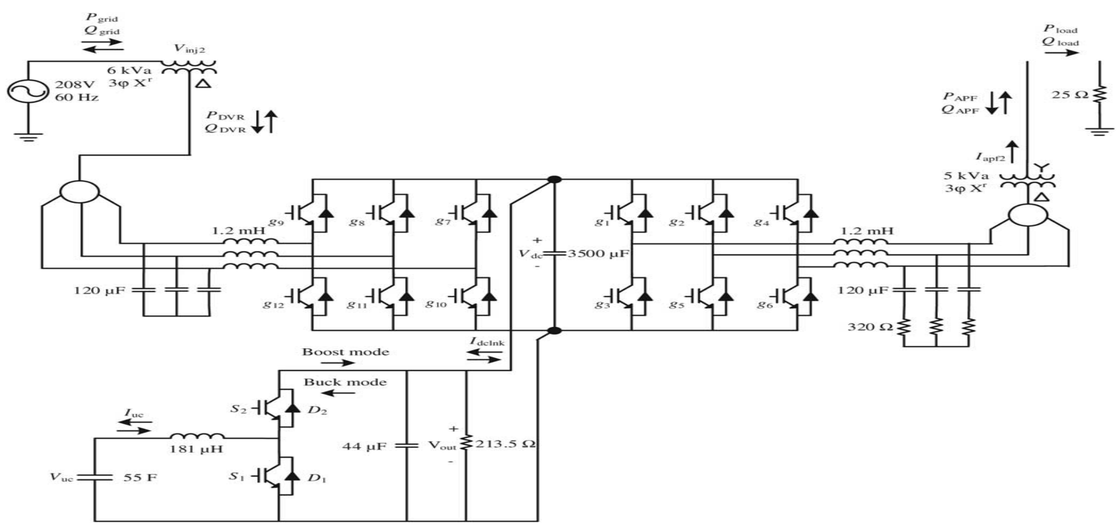

Fig. 2. Model of power conditioner with UCAP energy storage

IV.UCAPAND BIDIRECTIONAL DC-DC CONVERTER

UCAP Bank Hardware Setup:

UCAPs can deliver very high power in a short time span; they have higher power density and lower energy density when compared to Li-ion batteries .The major advantage UCAPs have over batteries is their power density characteristics, high number of charge-discharge cycles over their life time 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. It is proposed that UCAPs are currently viable as short term energy storage for bridging power link range in the seconds to few minutes time scale. The choice of the number of UCAPs necessary for providing grid support depends on the amount of support needed, terminal voltage of the UCAP, dc-link voltage and distribution grid voltages. In the present case the choice was made based on the following parameters. It is clear that the dc-link voltage needs to be 260V for the 208Vdistribution grid for optimal performance of the inverter. The terminal voltage of each BMOD0165P048 module is 48Vwhich means connecting three modules in series would bring the initial voltage of the UCAP bank to 144V and connecting four modules in series would bring the initial voltage of the UCAP bank to 192V. For a 260V dc-link voltage these two options are ideal for integrating the UCAP bank through the dc-dc converter since the duty ratio of the converter would be either too high for other cases. It is cost effective as well to use 3modules in the UCAP bank when compared to 4modules. In this paper, the experimental setup consists of three48V, 165F UCAPs (BMOD0165P048) manufactured by Maxwell Technologies which are connected in series.

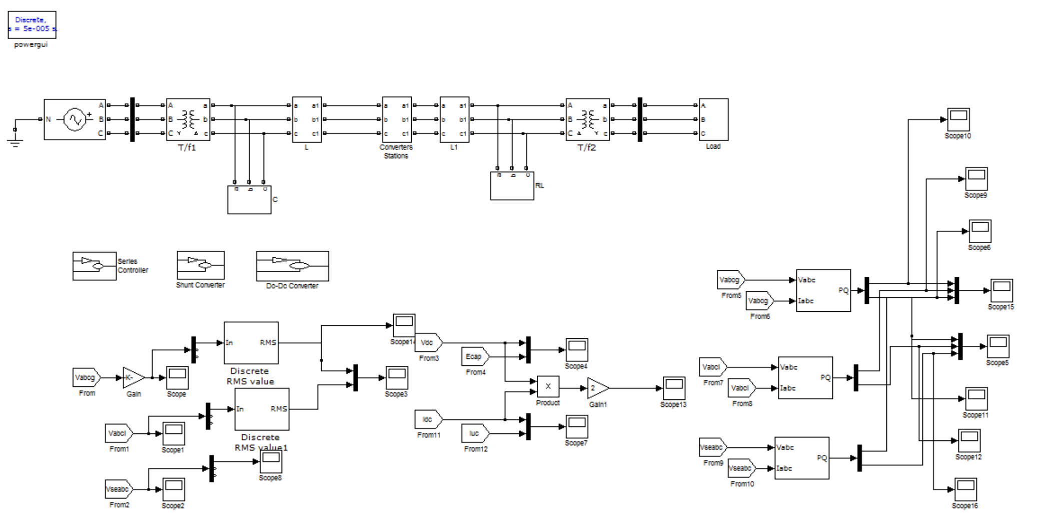

Fig.3 Simulink circuit of Proposed Model

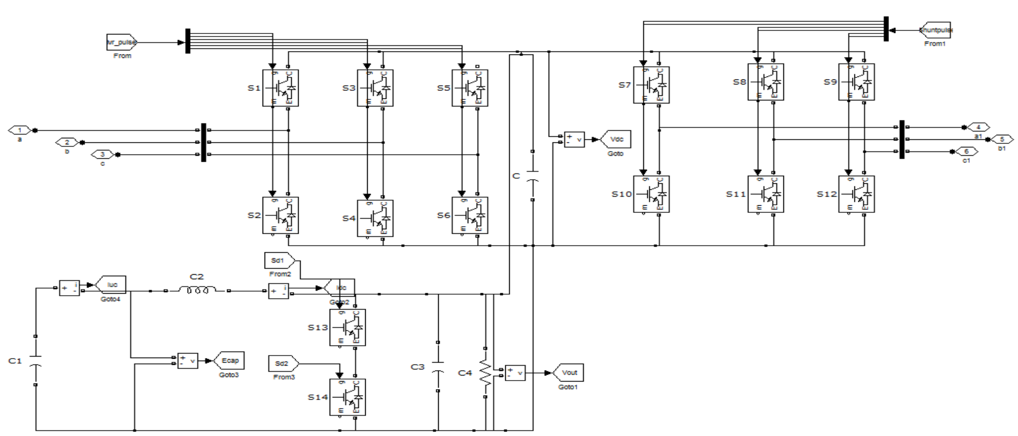

Fig.4 Simulink circuit of Converter Station

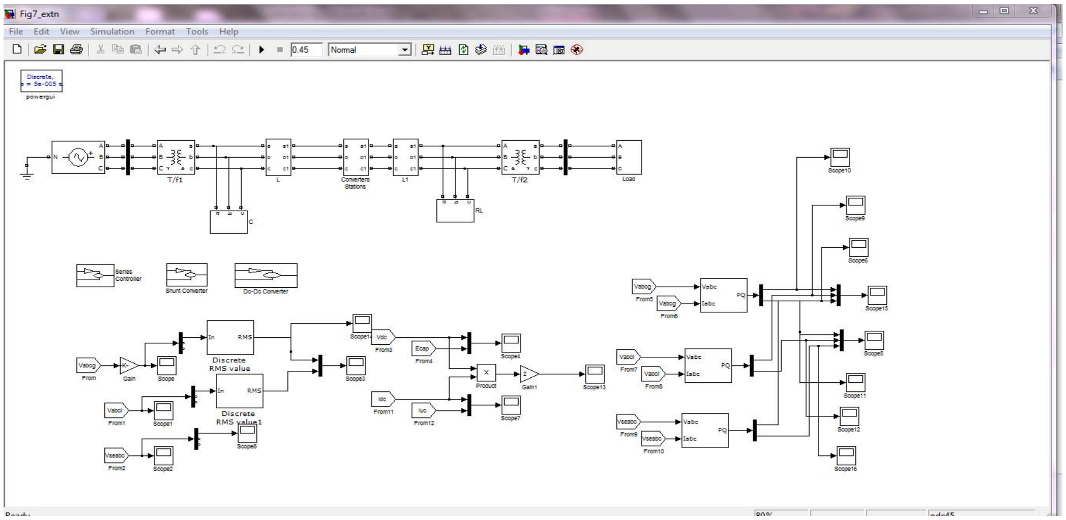

Fig.5 Simulink circuit of proposed model using fuzzy controller

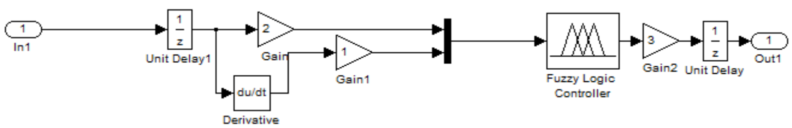

Fig.6 Simulink circuit of dc-dc converter using Fuzzy controller

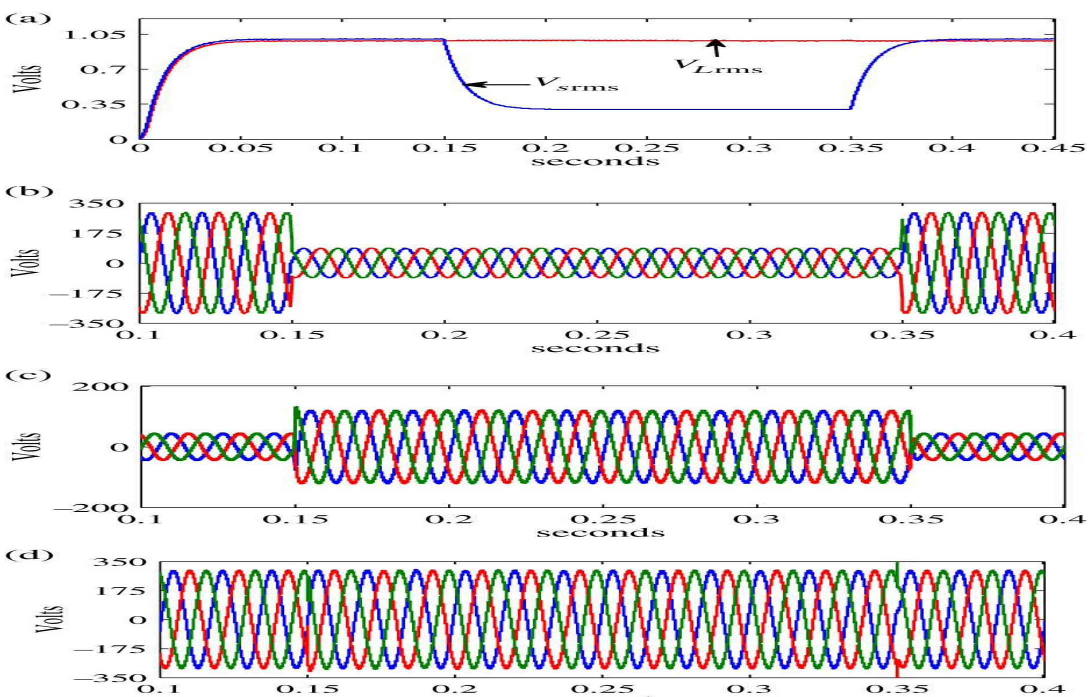

Fig.7 Output waveforms

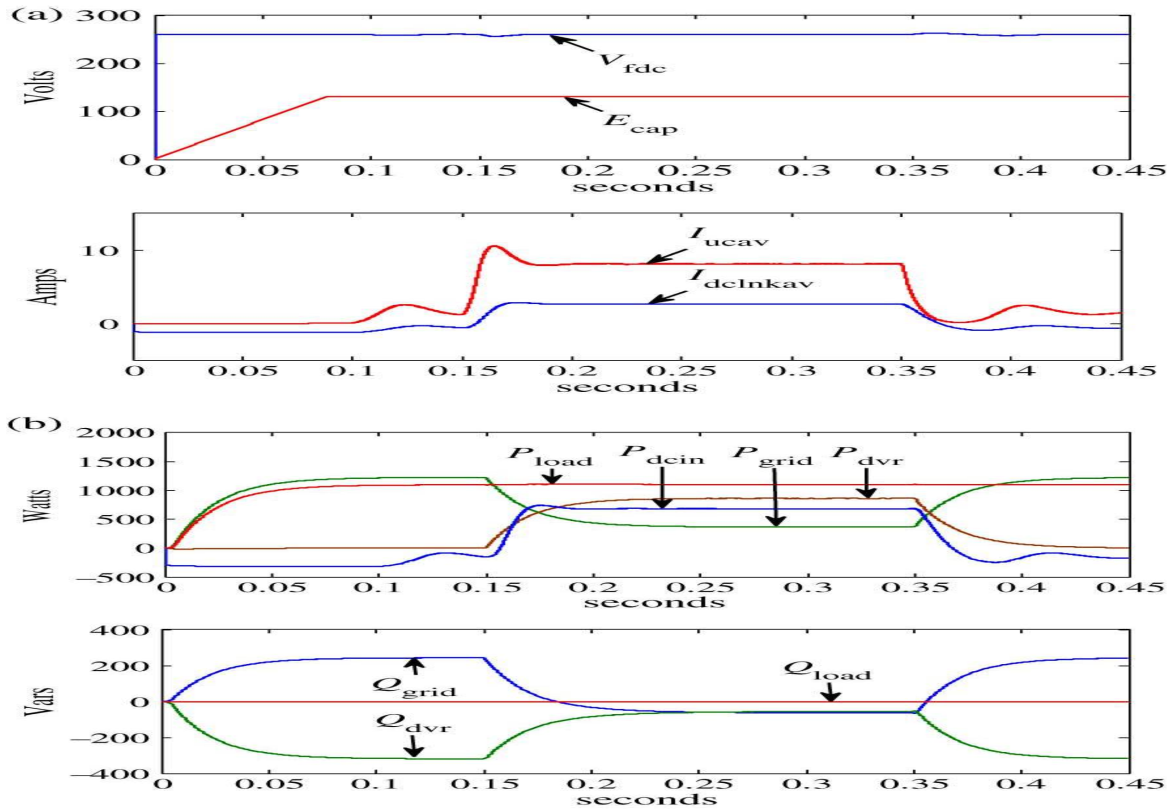

Fig. 8 (a) Currents and voltages of dc–dc converter. (b) Active and reactive power of grid, load, and inverter
During voltage sag.

CONCLUSION

In this paper, the concept of integrating UCAP-based rechargeable energy storage to a power conditioner system to improve the power quality of the distribution grid is presented. With this integration, the DVR portion of the power conditioner will be able to independently compensate voltage sags and swells and the APF portion of the power conditioner will be able to provide active/reactive power support and renewable intermittency smoothing to the distribution grid. UCAP integration through a bidirectional dc–dc converter at the dc-link of the power conditioner is proposed. The control strategy of the series inverter (DVR) is based on in phase compensation and the control strategy of the shunt inverter (APF) is based on $id - iq$ method. Designs of major components in the power stage of the bidirectional dc–dc converter are discussed. Average current mode control is used to regulate the output voltage of the dc–dc converter. results are observed for both the converters that is PI and neuro fuzzy controllers.

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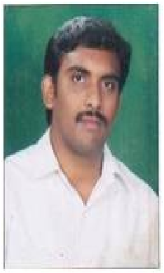

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