International Journal of Research

International Journal of Research (IJR)

e-ISSN: 2348-6848, p- ISSN: 2348-795X Volume 2, Issue 10, October 2015

Available at http://internationaljournalofresearch.org

Enhancement of Power Quality in Distribution System by Ultra Capacitor Integrated Power Conditioner

G. Akhil
M-Tech Scholar, Department of EEE, Gudlavalleru Engineering College, Gudlavalleru, Krishna (Dt), A.P, India.
akhilgudiwada606@Gmail.Com
D. Srinivasa Rao
Associate Professor, Department of EEE, Gudlavalleru Engineering College, Gudlavalleru, Krishna (Dt), A.P, India .
dsrinivasarao1993@Gmail.Com
K. Bhavya
Assistant Professor, Department of EEE, BVRIT Hyderabad for women, Hyderabad, Telangana, India.
bhavya.eee.08@gmail.com

Abstract:

With increasing applications of nonlinear and electronically switched devices in distribution systems and industries, power-quality (PQ) problems have become serious concern. 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. In this study an energy storage system (ESS) supply power demand using a DC/DC boost converter respectively. The integration helps in providing active/reactive power support, intermittency smoothing, and sag/swell compensation. UCAPs have low energy density, high power density, and fast charging/discharging rates, which are all ideal characteristics for meeting high power low energy events like sag/swells. We focus on a fuzzy logic control (FLC) algorithm integrated into the power conditioning unit (PCU) for Ultra-capacitor (UC) integrated system. The control strategy is capable of managing power flow from UC bank and keeps the DC bus voltage around its nominal value.

Index Terms—dc–dc converter; dynamic voltage restorer (DVR); energy storage integration; sag/swell; ultra capacitors (UCAP); fuzzy logic control.

I. INTRODUCTION

Power quality problems are arising due to increased use of the non-linear (power electronic) loads, the faults in distribution network, the starting and stopping of heavy loads. In that, load harmonic currents, voltage sag, swell, and reactive power are considered as major power quality problems.

It is very possible that several kinds of power quality disturbances are in a distribution system and it is therefore important to introduce UPQC (Unified Power Quality Conditioner). UPQC is the emerging device of Custom Power, which combines the functions of series voltage compensator, shunts current compensator and energy storage device.

One of the serious problems in electrical systems is the increasing number of electronic components of devices that are used by industry as well as residences. These devices, which need high-quality energy to work properly, at the same time, are the most responsible ones for injections of harmonics in the distribution system.

Therefore, devices that soften this drawback have been developed. One of them is the UPQC, It consists of a shunt active filter together with a series-active filter. This combination allows a simultaneous compensation of the load currents and the supply voltages, so that compensated current drawn from the network and the compensated supply voltage delivered to the load is Sinusoidal, balanced and minimized. The series- and shunt active filters are connected in back-to-back configuration, in which the shunt converter is responsible for regulating the common DC-link voltage. In this paper energy storage integration into the power conditioner topology is being proposed which will allow the integrated system to provide additional functionality.

Energy storage systems (ESS) for power utility applications have received considerable attention due to their characteristics such as rapid response (milliseconds), high power (Megawatts) and high efficiency. Energy storage systems can provide improved system reliability, dynamic stability and enhanced power quality. Emerging power electronics applications in the millisecond and longer time are projected to have a broad application need for electrochemical chemical double layer capacitors (UCAPs), especially for compact sizes as this technology has the potential of achieving energy densities of many kJ/kg for discharge times of seconds.

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 require active power support in the *seconds* to *minutes* time scale like voltage sags/swells, active/reactive power support, and renewable intermittency smoothing.

For these controllers, conventional PI controllers are widely applied. This is mainly because PI controllers have simple control structures, and are simple to maintain. The drawback of such PI controllers is that their performance degrades as the system operating conditions change. The fuzzy logic controller has a number of distinguishing advantages over conventional controllers. It is not so sensitive to variations of system structure, parameters and operation points and can be easily implemented in a large scale nonlinear system. Furthermore, the fuzzy logic controller is a sophisticated technique that is easy to design and implement. In addition, in the past decade, many researchers have attempted to combine conventional PID controllers with fuzzy logic to improve controller performance.

II. THREE-PHASE INVERTERS

A. 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 Fig.1.

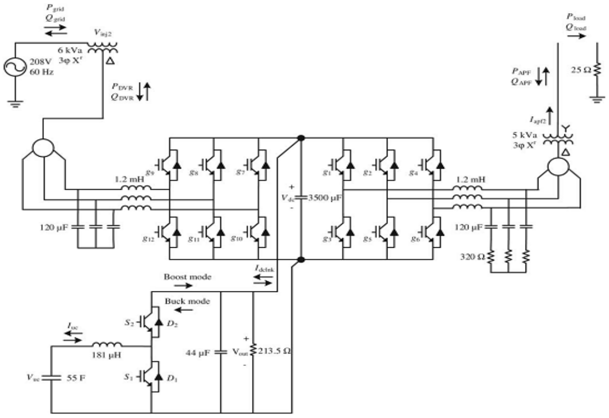


Fig.1. Model of power conditioner with UCAP energy storage.

The goal of this project is to provide the integrated power conditioner and UCAP system with active power capability.

1) to compensate temporary voltage sag (0.1–0.9 p.u.) and swell (1.1–1.2 p.u.), which last from 3 s to 1 min; and 2)to provide active/reactive support and renewable intermittency smoothing, which is in the seconds to minutes time scale.

B. Controller Implementation

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

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

$$\begin{bmatrix} V_{\mathrm{ref}a} \\ V_{\mathrm{ref}b} \\ V_{\mathrm{ref}c} \end{bmatrix} = m * \begin{bmatrix} \left(\sin\theta - \frac{V_{sa}}{169.7}\right) \\ \left(\sin\left(\theta - \frac{2\pi}{3}\right) - \frac{V_{sb}}{169.7}\right) \\ \left(\sin\left(\theta + \frac{2\pi}{3}\right) - \frac{V_{sc}}{169.7}\right) \end{bmatrix} \quad (2)$$

$$P_{\mathrm{dvr}} = 3V_{\mathrm{inj2}a(\mathrm{rms})} I_{La(\mathrm{rms})} \cos\ \varphi$$

$$Q_{\mathrm{dvr}} = 3V_{\mathrm{inj2}a(\mathrm{rms})} I_{La(\mathrm{rms})} \sin\ \varphi. \quad (3)$$

These voltages are normalized to unit sine waves using line–neutral system voltage of 415 Vrms as reference and compared with unit sine waves in-phase with actual system voltages Vs from (2) to find the injected voltage references Vref 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 Vinj2 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 Vinj2a and load current ILa and ϕ is the phase difference between the two waveforms.

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

$$Q_{\mathrm{ref}} = -\frac{3}{2} v_{\mathrm{sq}} i_{\mathrm{dref}} \quad (4)$$

$$\begin{bmatrix} i_{\mathrm{ref}a} \\ i_{\mathrm{ref}b} \\ i_{\mathrm{ref}c} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_{\mathrm{dref}} \\ i_{\mathrm{qref}} \end{bmatrix} \quad (5)$$

The shunt inverter controller implementation is based on the id − iq method, which is modified to provide active and reactive power compensation, such that id controls the reactive power and iq controls the active power. Therefore, based on the references for active and reactive powers Pref and Qref, the reference currents iqref and idref in d–q domain can be calculated using (4), where vsq is the system voltage in q-domain and the reference currents are calculated using (5).

III. BIDIRECTIONAL DC–DC CONVERTER

A bidirectional dc–dc converter is required as an interface between the UCAP and the dc-link, since the UCAP voltage varies with the amount of energy discharged, while the dc-link voltage has to be stiff. The model of the bidirectional dc–dc converter and its controller are shown in Fig. 2(a). The dc–dc converter should operate in Discharge mode, while providing active/reactive power support and voltage sag compensation.

The dc–dc converter should also be able to operate in bidirectional mode to be able to charge or absorb additional power from the grid during intermittency smoothing. In this paper, the bidirectional dc–dc converter acts as a boost converter, while discharging power from the UCAP and acts as a buck converter while charging the UCAP from the grid.

Average current mode control, which is widely explored in literature , is used to regulate the output voltage of the bidirectional dc–dc converter in both Buck and Boost modes while charging and discharging the UCAP bank. This method tends to be more stable when compared with other methods like voltage mode control and peak current mode control.

IV. Ultra Capacitor (UCAP)

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 [18], [19]. 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. In [20], it is proposed that UCAPs are currently viable as short-term energy storage for bridging power in kilowatt range in the *seconds* to *few minutes* timescale. 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. For a 260-V dc-link voltage, it is practical and cost-effective to use three modules in the UCAP bank. Assuming that the UCAP bank can be discharged to 50% of its initial voltage (*V*uc,ini) to final voltage (*V*uc,fin) from 144 to 72 V, which translates to depth of discharge of 75%, the energy in the UCAP bank available for discharge is given by

$$E_{\text{UCAP}} = \frac{1}{2} * C * \frac{\left(V^2_{\text{uc, ini}} - V^2_{\text{uc,fin}}\right)}{60} \text{ W min}$$

$$E_{\text{UCAP}} = {}^{1}\!/_{2} * {}^{165}\!/_{3} * {}^{\left(144^2 - 72^2\right)}\!/_{60}$$

$$= 7128 \text{ W min.}$$

V. Fuzzy Logic Controller

In a fuzzy logic controller, the control action is determined from the evaluation of a set of simple linguistic rules. The development of the rules requires a thorough understanding of the process to be controlled, but it does not require a mathematical model of the system. The objectives include excellent rejection of input supply variations both in utility and in generating system and load transients. Expert knowledge can also be participated with ease that is significant when the rules developed are intuitively inappropriate [7]. The rule base developed is reliable since it is complete and generated sophistically without using extrapolation. In this project, fuzzy control is used to control the firing angle for the switches of the VSI of UPQC. In this design, the fuzzy logic based UPQC has two inputs 'change in voltage(ΔV)' and 'change in current(ΔI)' and one control output(ΔU). Firstly the input values will be converting to fuzzy variables. This is called fuzzification. After this, fuzzy inputs enter to rule base or interface engine and the outputs are sent to defuzzification to calculate the final outputs. These processes are demonstrated in Fig. 3. Here seven fuzzy subsets have been used for two inputs. These are: PB (positive big), PM (positive medium), PS (positive small), ZE (zero), NS (negative small), NM (negative medium) and NB (negative big). We use Gaussian membership functions [8] and 49 control rules are developed, which are shown in table 1.

Fuzzification: It is the process of representing the inputs as suitable linguistic variables .It is first block of controller and it converts each piece of input data to a degree of membership function. It matches the input data with conditions of rules and determines how well the particular input matches the conditions of each rule.

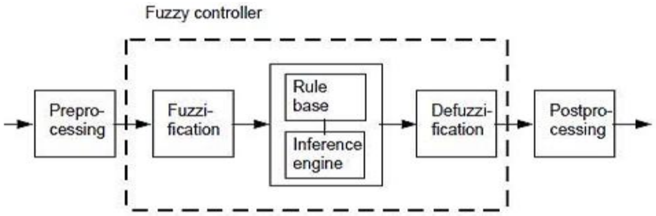


Fig.2. Fuzzy control block diagram.

Table I
Control Rules

ΔI / ΔV	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NM	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

The membership functions for the inputs (for ΔV and ΔI) are shown in Fig.4 and Fig.5. The number of fuzzy levels is not fixed and it depends on the input resolution needed in an application. The larger the number of fuzzy levels, the higher is the input resolution. The fuzzy control implemented here uses sinusoidal fuzzy-set values. Decision making: The control rules that associate the fuzzy output to the fuzzy inputs are derived from general knowledge of the system behavior. However, some of the control actions in the rule table are also developed using “trial and error” and from an “intuitive” feel of the process to be controlled. In this effort, the control rules for the UPQC in Table 1 resulted from the understanding of UPQC’s behavior and experimental tests of its VSI’s performance.

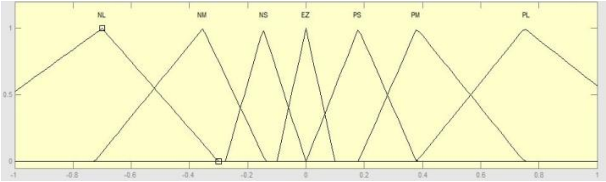


Fig.4. Membership function for source voltage

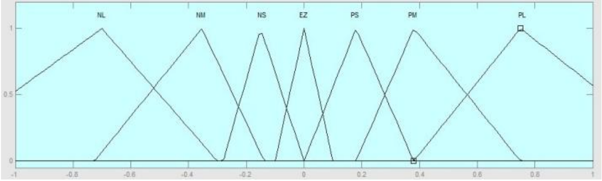


Fig.5. Membership function for change in voltage ΔV.

Defuzzification: It is the Process of converting fuzzy flied output into a crisp value. In the defuzzification operation a logical sum of the results from each of the rules performed. This logical sum is the fuzzy representation of the change in firing angle (output). A crisp value for the change in firing angle is calculated. Correspondingly the grid current changes and improves the power quality.

V.MATLAB/SIMULINK RESULTS

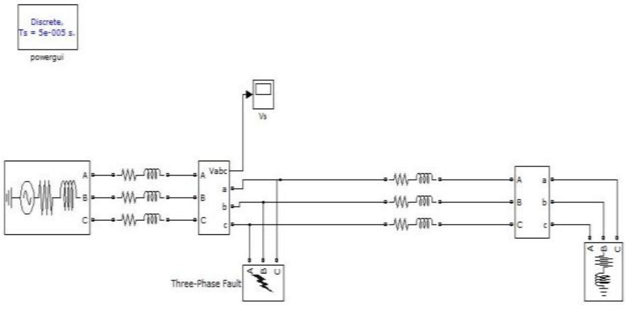


Fig.6.Matlab/Simulink Model Of Without Compensation.

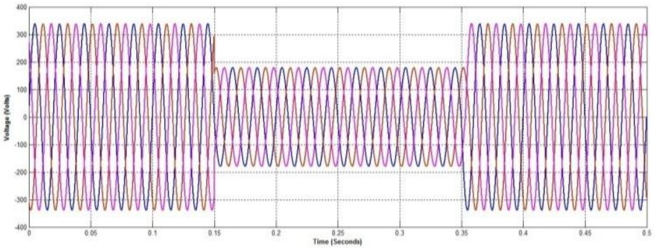
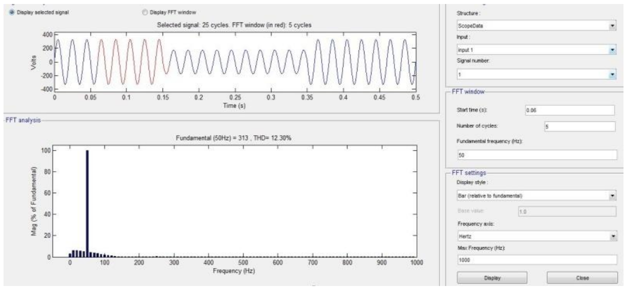


Fig.7. Sources Voltage During Sag.



Selected signal: 25 cycles. FFT window (in red): 5 cycles

Fundamental (50Hz) = 313 , THD= 12.30%

Structure : ScopeData
Input : input 1
Signal number: 1
FFT window
Start time (s): 0.06
Number of cycles: 5
Fundamental frequency (Hz): 50
FFT settings
Display style : Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

Fig.8.THD for Load Voltage Without Compensation.

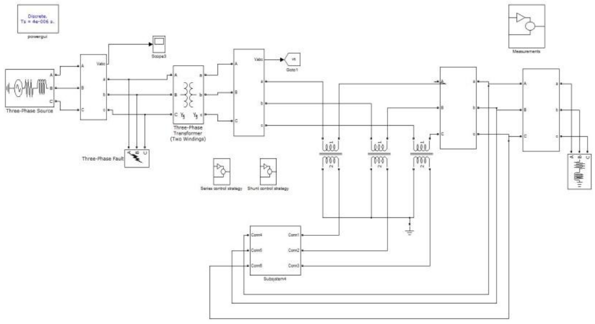


Fig.9.Matlab/Simulink Model With Compensation.

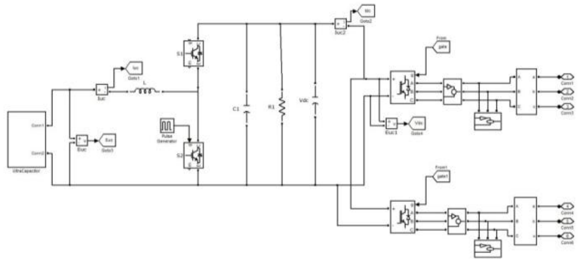


Fig.10.Simulink Model of the Bidirectional Dc–Dc Converter and Its Controller.

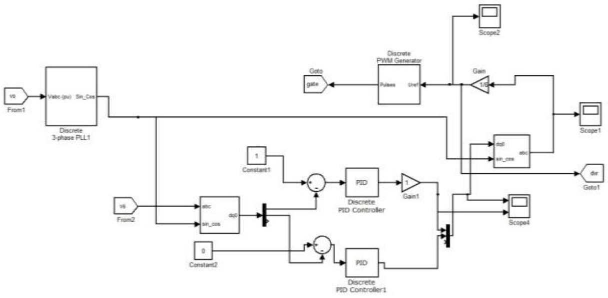
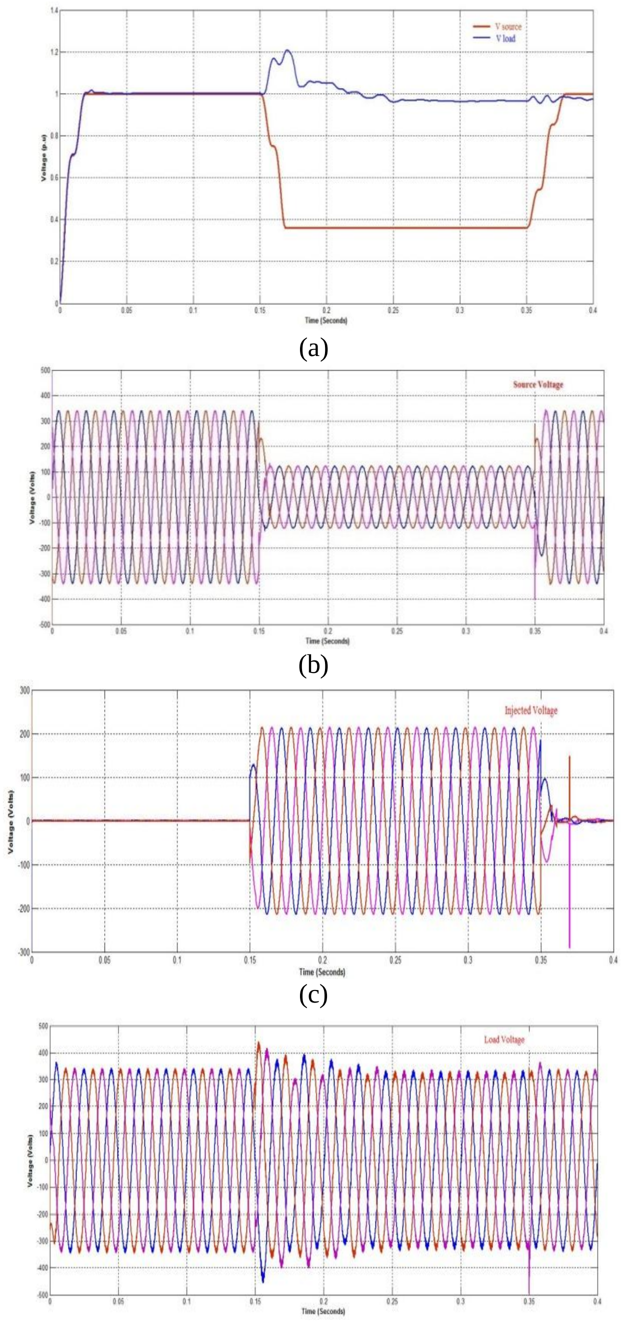


Fig.11.Control Strategies of DVR with PID Controller.



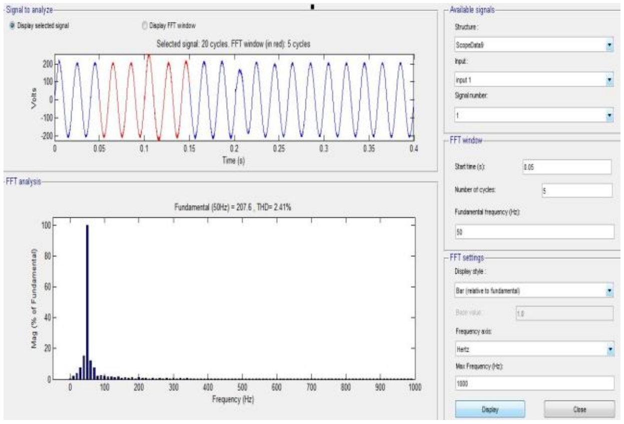
(a)

(b)

(c)

(d)

Fig.12. (a) Source and Load Rms Voltages. (B) Source Voltages. (C) Injected Voltages (D) Load Voltages During Sag.



Selected signal: 20 cycles. FFT window (in red): 5 cycles

Fundamental (50Hz) = 207.6 , THD= 2.41%

Structure : ScopeData9

Input : input 1

Signal number: 1

Start time (s): 0.05

Number of cycles: 5

Fundamental frequency (Hz): 50

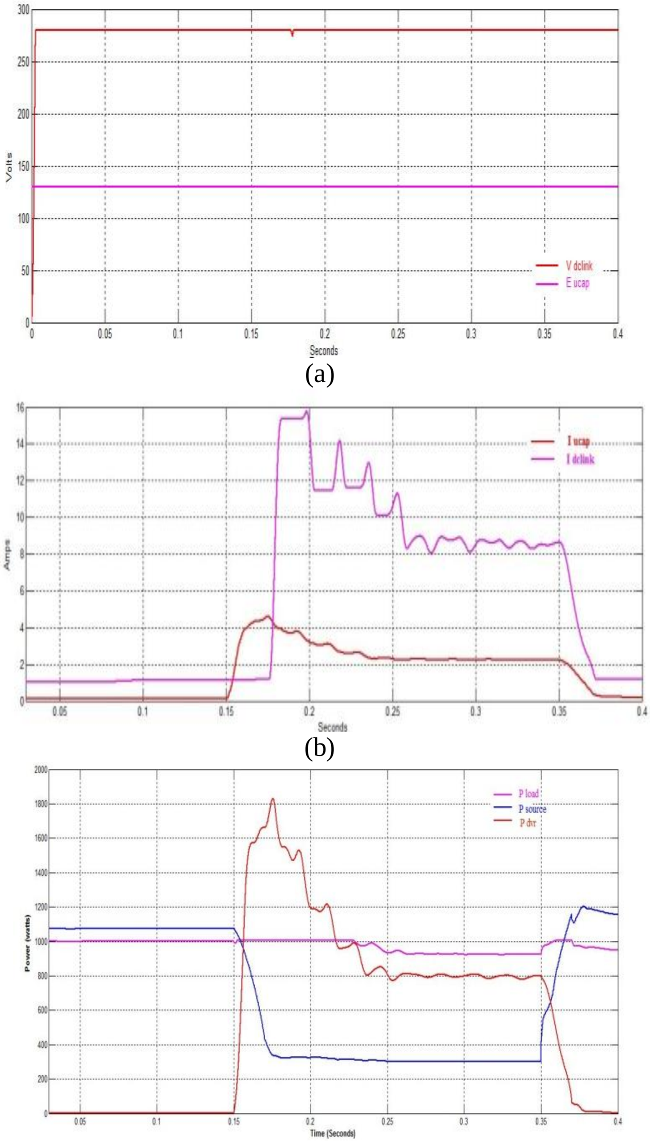
Display style : Bar (relative to fundamental)

Base value: 1.0

Frequency axis: Hertz

Max Frequency (Hz): 1000

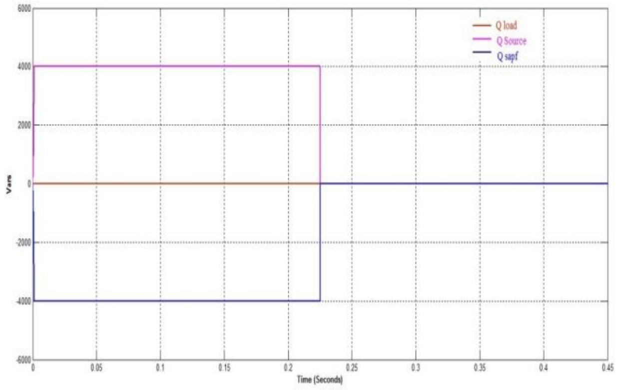
Fig.13.THD for Load Voltage with Compensation.



(a)

(b)

(c)



(d)

Fig.14. (A) Voltages of Dc–Dc Converter. (B) Currents of Dc-Dc Converter (C) Active Power of Source, Load and DVR (D). Reactive Power of Load, Source and SAAPF during Voltage Sag.

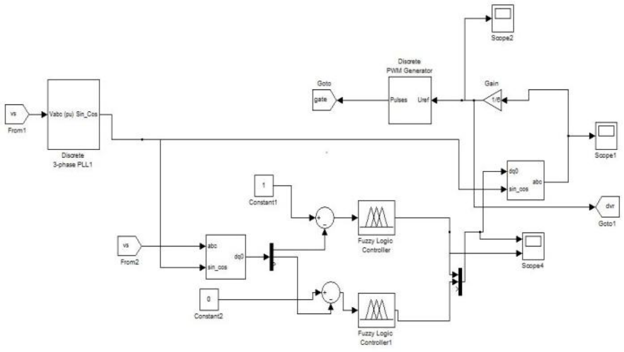
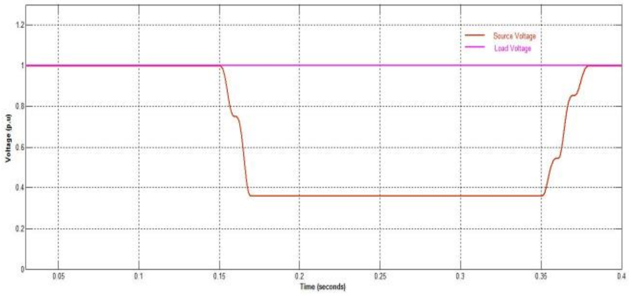
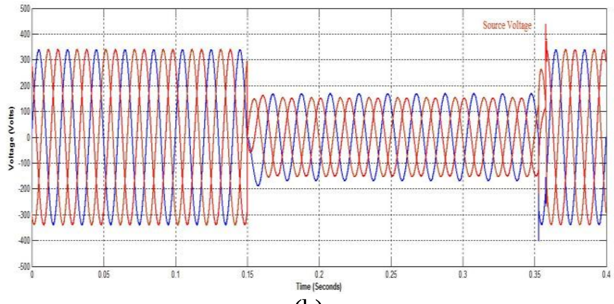


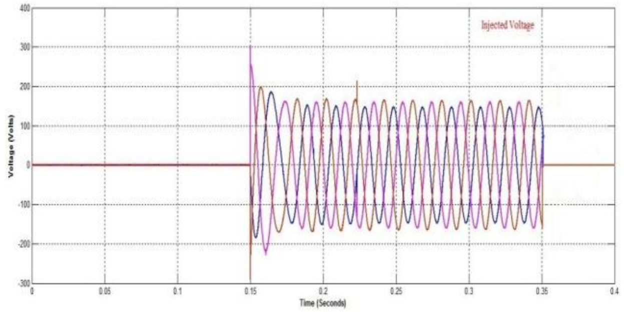
Fig.15.Control Strategies of DVR With Fuzzy Logic Controller.



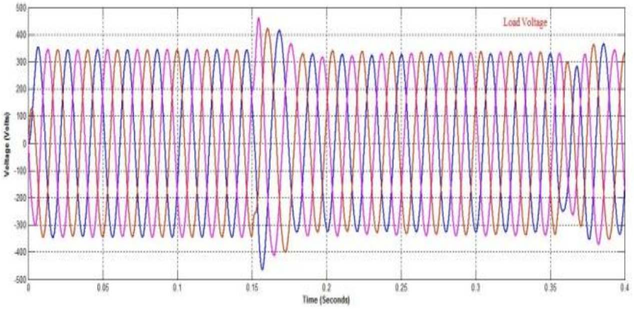
(a)



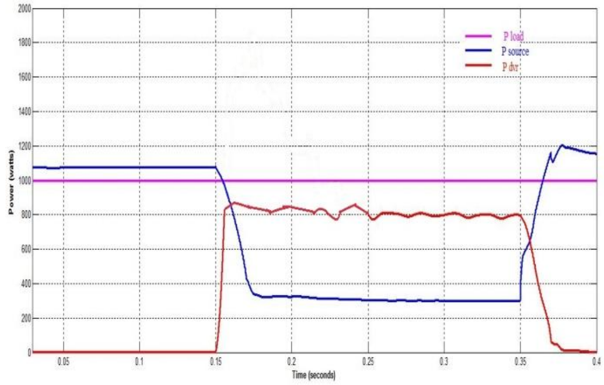
(b)



(c)

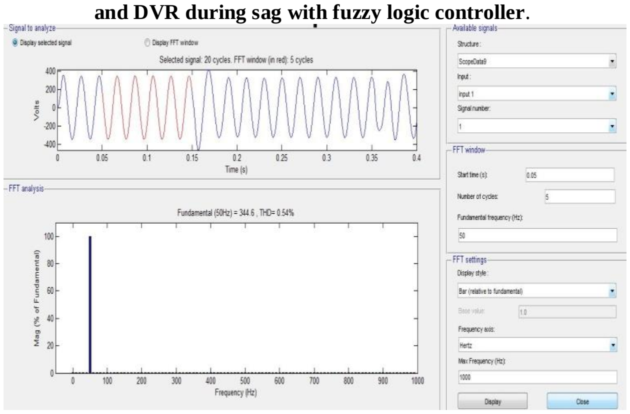


(d)



(e)

Fig.16. (a) Source and load rms voltages. (b) Source voltages. (c) Injected voltages (d) Load voltages (e) Active power of source, load and DVR during sag with fuzzy logic controller.


Signal to analyze

● Display selected signal ○ Display FFT window

Selected signal: 20 cycles. FFT window (in red): 5 cycles

FFT analysis

Fundamental (50Hz) = 344.6 , THD= 0.54%

Available signals

Structure : ScopeData9

Input : input 1

Signal number: 1

FFT window

Start time (s): 0.05

Number of cycles: 5

Fundamental frequency (Hz): 50

FFT settings

Display style : Bar (relative to fundamental)

Base value: 1.0

Frequency axis: Hertz

Max Frequency (Hz): 1000

Fig.17.THD for Load Voltage with Compensation and Fuzzy Logic Control.

VI. 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. The controllers mainly used for power quality improvement are PID controller and fuzzy logic controller. Hence as compared to the response obtained with PID controller, fuzzy controller has great advantage of flexibility.

REFERENCES

[1] Deepak Somayajula and Mariesa L.Crow “An Ultracapacitor Integrated power conditioner for intermittency smoothing and improving power quality of Distribution Grid” IEEE Trans. on Sustainable Energy, vol. 5, no. 4, Oct. 2014.

[2] J. G. Nielsen, M. Newman, H. Nielsen, and F. Blaabjerg, “Control and testing of a dynamic voltage restorer (DVR) at medium voltage level,” IEEE Trans. Power Electron., vol. 19, no. 3, pp. 806–813, May 2004.

[3] V. Soares, P. Verdelho, and G. D. Marques, “An instantaneous active and reactive current component method for active filters,” IEEE Trans. Power Electron., vol. 15, no. 4, pp. 660–669, Jul. 2000.

[4] H. Akagi, E. H. Watanabe, and M. Aredes, Instantaneous Reactive Power Theory and Applications to Power Conditioning, 1st ed. Hoboken, NJ, USA: Wiley/IEEE Press, 2007.

[5] K. Sahay and B. Dwivedi, “Supercapacitors energy storage system for power quality improvement: An overview,” J. Energy Sources, vol. 10, no. 10, pp. 1–8, 2009.

[6] B. M. Han and B. Bae, “Unified power quality conditioner with super-capacitor for energy storage,” Eur. Trans. Elect. Power, vol. 18, pp. 327–343, Apr. 2007.

[7] P. F. Ribeiro, B. K. Johnson, M. L. Crow, A. Arsoy, and Y. Liu, “Energy storage systems for advanced power applications,” Proc. IEEE, vol. 89, no. 12, pp. 1744–1756, Dec. 2001.

[8] A. B. Arsoy, Y. Liu, P. F. Ribeiro, and F. Wang, “StatCom-SMES,” IEEE Ind. Appl. Mag., vol. 9, no. 2, pp. 21–28, Mar. 2003.

[9] J. Rittershausen and M. McDonagh, Moving Energy Storage from Concept to Reality: Southern California Edison’s Approach to Evaluating Energy Storage [Online]. Available:http://www.edison.com/content/ dam/ eix/ documents/innovation/smart-grids/Energy-Storage-Concept-toReality-Edison.pdf, accessed on 15 Jul., 2014.

[10] M. Branda, H. Johal, and L. Ion, “Energy storage for LV grid support in Australia,” in Proc. IEEE Innov. Smart Grid Tech. Asia (ISGT), Nov. 13–16, 2011, pp. 1–8.

[11] W. Li, G. Joos, and J. Belanger, “Real-time simulation of a wind turbine generator coupled with a battery supercapacitor energy storage system,” IEEE Trans. Ind. Electron., vol. 57, no. 4, pp. 1137–1145, Apr. 2010.

[12] P. Thounthong, A. Luksanasakul, P. Koseeyaporn, and B. Davat, “Intelligent model-based control of a standalone photovoltaic/fuel cell power plant with supercapacitor energy storage,” IEEE Trans. Sustain. Energy, vol. 4, no. 1, pp. 240–249, Jan. 2013.

[13] X. Li, D. Hui, and X. Lai, “Battery energy storage station (BESS)-based smoothing control of photovoltaic (PV) and wind power generation fluctuations,” IEEE Trans. Sustain. Energy, vol. 4, no. 2, pp. 464–473, Apr. 2013.

[14] J. Tant, F. Geth, D. Six, P. Tant, and J. Driesen, “Multiobjective battery storage to improve PV integration in residential distribution grids,” IEEE Trans. Sustain. Energy, vol. 4, no. 1, pp. 182–191, Jan. 2013.

[15] Y. Ru, J. Kleissl, and S. Martinez, “Storage size determination for grid connected photovoltaic systems,” IEEE Trans. Sustain. Energy, vol. 4, no. 1, pp. 68–81, Jan. 2013.