International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

June 2014	Issue 19	Volume 6	Number 2	Pages 64-70

IMPROVE POWER QUALITY ON DISTRIBUTION POWER GRIDS USING ULTRA CAPACITOR AND DSTATCOM

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Abstract- A distribution power grid is subjected to a contingency such as fault, the voltage of system may be severely deteriorated and becomes harmonically. Hence, the concerns about Power Quality (PQ) issues grow with large fault occurring in the distribution power system. Distribution STATCOM (DSTATCOM) is nominated as a fast-response and robust device for mitigation of instability and oscillation problems. These capabilities of DSTATCOM can improved by inclusion of relatively fast-acting Energy Storage Systems (ESS) such as Ultra-Capacitor (UC). Ultra-capacitors have distinct potential advantages for energy storage that make them almost unbeatable in many applications. The aim of this paper is to investigate the application of DSTATCOM accompanied with UC for PQ improvements in the case of three-phase fault occurring in the power distribution grids. The Voltage and Harmonics in power distribution systems are the main factors for PQ. The integrated UC-DSTATCOM topology, improves simultaneously the transient specification of a power system such as voltage and harmonic response. So in this paper the voltage profile and harmonic components in presence of the Normal Capacitor (AC Capacitor) and UC-DSTATCOM (Ultra capacitor beside DSTATCOM) are analyzed and compared with each other using "SimPowerSystems" of MATLAB/SIMULINK.

Keywords: Distribution Power Grid, UC-DSTATCOM, Normal Capacitor, Voltage Sag, Harmonic Components.

I. INTRODUCTION

Providing energy for customers with certain technical requirements is the aim of power systems. PQ is the most important part of these requirements that related to the system capability of maintaining operation in the case of contingencies and unexpected failures of any of the components. For this reason, maintaining the main characteristic of a power system such as Voltage waveform and harmonic components is one of the main issues of the system. Thus, suitable control system is required in order to keep the system PQ above the admissible minimum level during the dynamic transients.

Otherwise, serious problems could occur in the utility system and perhaps the disturbance increase would lead to the system collapse. Voltage sags, harmonic distortion, flicker, and interruption of power supply are the most common problems. The efficient use of the electric systems while maintaining security levels requires more sophisticated control schemes using advanced technologies [1].

All the above considerations lead to the necessity of enhancing the performance of the PQ correction, so to cope with the challenges imposed by modern power systems. In this sense, new improvements have made on the conventional methods for PQ. Nevertheless, all these improvements not enough to satisfy the high requirements established and need to seek solutions that are more effective emerges [2].

There are many solutions in mitigating the PQ problems at a power distribution system such as using surge arresters, active power filters, isolation transformer, uninterruptible power supply, and Static VAR Compensator (SVC). A group of controllers together called Custom Power Devices (CPD), which includes the DSTATCOM, Dynamic Voltage Restorer (DVR), and Unified Power Quality Conditioner (UPQC), used for compensating the PQ problems in the current and voltage respectively in very short time. In recent years, it has seen gradually that ESS, advanced solutions such as UC, has received significant interest for high power utility applications. The rapid advances in superconductive technology have permitted such devices of reasonable size to be designed and commissioned successfully [3, 4].

Ultra capacitors have distinct potential advantages for energy storage that make them almost unbeatable in many applications because they have no moving parts, and require neither cooling nor heating, and because they undergo no internal chemical changes as part of their function, they are very efficient and robust. In addition, they require practically no maintenance and the lifetime measured in decades, with no lifetime degradation due to frequent and deep cycling. They have no significant fringe fields and they are intrinsically modular which enhances reparability and allows capacity to be easily incremented.

Ultra-capacitors store only a relatively modest quantity of energy, but they are capable of high power discharge rates and fast recharge [4]. The STATCOM is utilized based on the principle that regulates the voltage at its terminal with managing the amount of reactive power injected to or absorbed from the power system. By controlling the output voltage magnitude of the STATCOM, the reactive power will be exchanged between STATCOM and the transmission system [5].

Commonly speaking, FACTS device contain low frequency oscillation during ad system damping and adjust power position of the line [6].

By combining the technology of UCs with recent types of power electronic equipment, such as power converter based FACTS (Flexible Alternating Current Transmission Systems) controllers, may take advantage of the flexibility benefits provided by UCs and the high controllability provided by power electronics aiming at controlling and optimizing the performance of the electric system. A previous study of the dynamic performance of power converter based FACTS devices jointly with UC systems has suggested the use of Static Synchronous Compensators (DSTATCOM) as most adequate for PQ applications [7].

The current work presents an enhanced PQ scheme based on incorporating a DSTATCOM coupled with an UC. A detailed full model and a control algorithm based on a decoupled current control strategy of the improved compensator are proposed [8]. The rest of this paper organized as follows: Section II reviews the modeling of a power system including DSTATCOM-UCES. In section III, the problem corresponding to the transient response of the power system defined. A case study performed in section IV by using MATLAB/ SIMULINK on a distribution power grid in the case of a three phase to ground fault, which shows the effectiveness of the proposed method. Finally, paper concluded in section V.

II. MODELING OF PROPOSED SYSTEM

FACTS-based power electronic controllers for electric distribution systems, namely Custom Power (CP) devices, are able to enhance the Reliability and Quality of power provided to customers. A DSTATCOM is a fast response, solid-state power controller that provides flexible voltage control at the point of connection to the utility distribution feeder for PQ improvements [4].

A DSTATCOM mitigate voltage fluctuations such as sags, swells, transients to provide voltage regulation, power factor correction and harmonics compensation that consists of a three-phase inverter shunt connected to the distribution network by means of a coupling transformer and the corresponding control scheme, as depicted through the block diagram of Figure 1 [8].

Its topology allows the device to generate a set of three almost sinusoidal voltages at the fundamental frequency, with controllable amplitude and phase angle. The addition of UC energy storage through an appropriate interface to the DSTATCOM device allows supplying effectively extra active power and thus expanding its compensating actions so that the operation of the electric grid can improved.

The UC is a relative recent technology in the field of energy storage systems based on the electric double layer capacitor (EDLC or DLC). Operation construction and theory of a DLC can understood by examining schematic view of its internal components presented in Figure 2 [9]. The proposed model describes the terminal behavior of the EDLC (Electric Double Layer Capacitor) unit over the frequency range from DC to several thousand Hertz.

A DSTATCOM controller coupled with an UC acts as a synchronous three-phase machine. This ideal synchronous machine can generate AC voltage with controllable amplitude and phase angle at its terminals. Furthermore, this ideal controller has no inertia and its response is almost instantaneous [8]. Figure 3 illustrates the proposed model of DSTATCOM-UCES system. This model consists of the step-up coupling transformer, the line filter, the Voltage Source Inverter (VSI), the buck-boost converter and the bank of UCs [8].

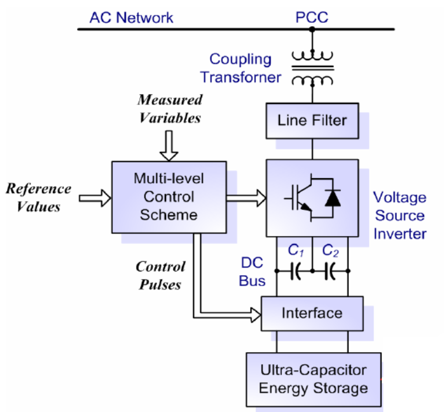

Figure 1. Basic circuit of a DSTATCOM/UCES [8]

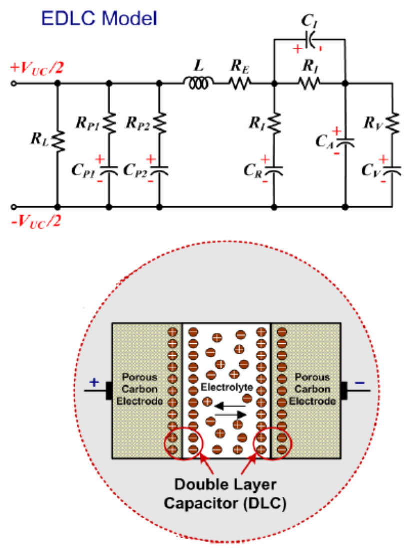

Figure 2. General structure and model of an UC unit [9]

The Buck-Boost converter plays an important role in order to fix the inverters input voltage through variation in duty cycle. The VSI presented corresponds to a DC to AC switching power inverter that uses Insulated Gate Bipolar Transistor (IGBT) in order to gain high frequency switching capability and appropriate power transmission.

In addition, the output voltage control of the DSTATCOM-UCES can achieved through Pulse Width Modulation (PWM) by using high-power fast-switched IGBTs. The inverter structure is based on a three phase Sinusoidal Pulse Width Modulation (SPWM) while the switching frequency is 10 kHz. In this way, the harmonic performance of the inverter improved, also by using an appropriate filter in order to improve current THD of the system. Finally, the proposed system connection has achieved via a step up transformer.

The amount of energy that injected into the power grid by the UC is proportional with its capacitance and square of its terminal voltage that described as bellow [8]:

$$E_{UCB} = \frac{1}{2} C_{UCB} (V_{UCBi}{}^2 - V_{UCBf}{}^2) \quad (1)$$

The bidirectional DC-DC converter has two modes of operation, namely the buck or charge modes and the boost or discharge mode. In the charge mode, the chopper works as a step-down (Buck) converter.

This topology makes use of modulation of the switch T_{bck} (upper IGBT in the leg), while keeping the switch T_{bst} off at all times, in order to produce a power flow from the DSTATCOM DC bus to the UC bank. In the discharge mode, the chopper operates as a step-up (boost) converter in collaboration with the DC bus capacitors. This topology employs the modulation of the lower IGBT of the leg, i.e. T_{bst}, and maintains T_{bck} off all the time to produce a power flow from the UC bank to the DSTATCOM DC bus. A general expression relating the bidirectional chopper average output voltage V_{UCB} to the VSI average DC bus voltage V_d can be derived through Equation (2):

$$V_{UCB} = mV_d \quad (2)$$

while $0 < m < 1$ can be defined as bellow:
$m = D$ for the chopper in buck mode (charge).
$m = (1- D)$ for the chopper in boost mode (discharge).
where, D is the duty cycle for switching T_{bck} or T_{bst} according to the operation mode [8].

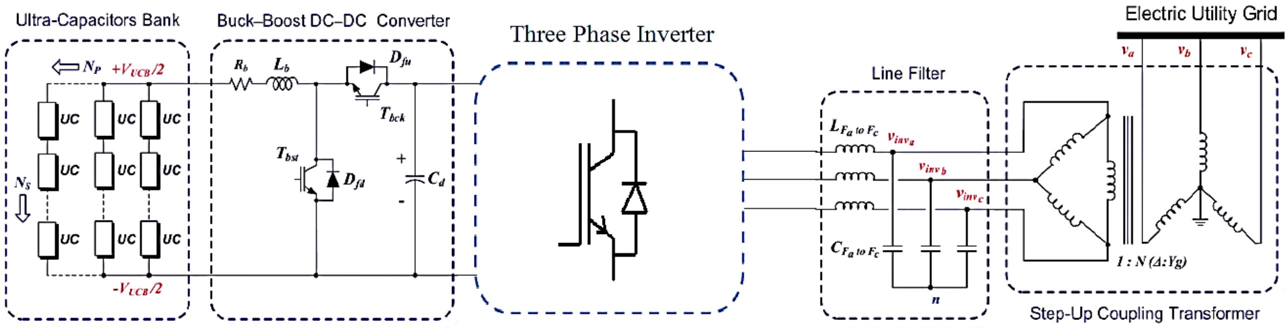

Figure 3. Detailed model of the proposed DSTATCOM-UCES [8]

III. PROBLEM STATEMENT

The Devices employed in the system should be able to timely track the voltage and harmonic deviations in direct consequence of any disturbances imposed to the system caused by different type of faults. Taking the advantage of DSTATCOM as a rapid FACTS device, the aim of this paper is to investigate the application Fast-acting ESS as a stabilizer of voltage and harmonic components oscillations in an example of distribution power system while a three-phase to ground fault occurs in a Bus. The performance of the power system with the presence of DSTATCOM and UC evaluated and compared while these devices omitted from the examined system.

UC is a fast-response ESS that can timely submit extra energy in order to alleviate dynamic disturbances. The current and voltage of the UC related as:

$$V_C = \frac{1}{C} \int_{t0}^{t} I_c \, d\tau + V_{C0} \quad (3)$$

where, C is the equivalent full capacitor of the UC and V_{C0} is the initial voltage of the capacitor.

DSTATCOM is an advanced compensator that can solve some problems of power system such as voltage sag as well as harmonic components of this device besides UC. It consists of a VSI; its DC side connected to a capacitor and its AC side to the network through a shunt transformer. Usually, low pass filters used at the output of inverter to mitigate unwanted harmonics.

IV. CASE STUDY AND SIMULATION RESULTS

In this section, the proposed method applied on a 13-Bus IEEE distribution grid, and voltage and harmonic in two different Buses has investigated with the presence of Normal Capacitor (AC Capacitor) and Ultra Capacitor beside DSTATCOM. Figure 4 shows the IEEE 13-bus distribution power system (a sample system) which is used in the simulation process. Line and transformer parameters of this network discussed in Tables 1 and 2, respectively.

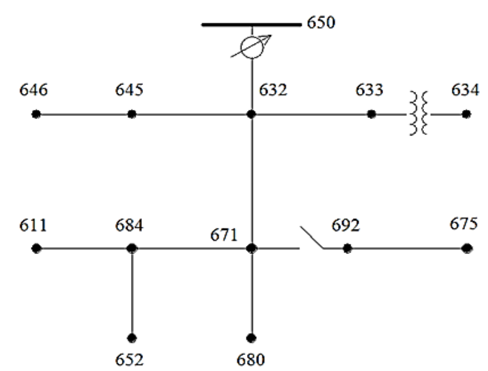

Figure 4. IEEE 13-bus distribution grid used in simulation

Table 1. Line parameters

Node A	Node B	Length (ft.)	Impedance(Ω/mile)
632	645	500	0.2066 + j0.4591
632	633	500	0.7526 + j1.1814
633	634	0	XFM-1
645	646	300	0.2066 + j0.4591
650	632	2000	0.3465 + j1.0179
684	652	800	1.3425 + j0.5124
632	671	2000	0.3465 + j1.0179
671	684	300	1.3238 + j1.3569
671	680	1000	0.3465 + j1.0179
671	692	0	Switch
684	611	300	1.3292 + j1.3475
692	675	500	0.7982 + j0.4463

Table 2. Transformers parameters

	kVA	kV-high	kV-low	R-%	X-%
Sub:	5,000	115-D	4.16-Gr. Y	1	8
XFM-1	500	4.16-Gr.W	0.48-Gr.W	1.1	2

Here the results (which simulated in MATLAB/SIMULINK) investigated in three sections. Firstly in presence of Normal Capacitor in the system and secondly in presence of UC-DSTATCOM. In the both cases, a three-phase to ground fault occurs at t =100/60 seconds and clear at t =135/60 seconds.

It is genuinely obvious, while contingencies such as three-phase to ground fault occurs in a distribution power grid, it effects on the vital features of the grid. As following figures illustrate, we can easily observe these affects.

In the first stage assumed a three-phase to ground fault occurs in bus number 646. (We assume the short circuit level in Bus number 646 is more than other buses).

Figures 5 and 6, represent the voltage sag at buses of 632 and 675 while a normal capacitor with capacity of 10 MVAR, has installed at bus 632. (The bus number 675 is furthest Bus compared to the placement of fault occurring).

Figure 7 represent the harmonic components of slack bus (bus 650) in presence of normal capacitor in the system. As it shows, it has many harmonics that caused because of inertia in power generation by the synchronous generator. In addition, these harmonics, especially the DC component, can be harmful for power system such as power transformer saturation. Whereas the normal capacitor has a low capacity, therefore has not so sensation to improve the voltage waveform and harmonic components on mentioned buses. In the next step, an UC-DSTATCOM (Ultra Capacitor beside DSTATCOM) has installed at bus 632. Figure 8 shows the distribution 13-Bus system which is simulated in MATLAB/SIMULINK in presence of UC-DSTATCOM.

Figures 9 and 10 show the voltage waveforms in buses number 632 and 675 after installation the UC-DSTATCOM in the system. As seen, voltage waveform significantly improved in considered buses. Besides, Figure 11 illustrates the harmonic components of slack bus (bus 650). As it shows, the harmonic components of slack Bus in presence of UC-DSTATCOM, is mainly improved and acceptable. Therefore, while a three-phase to ground fault occurs in a distribution power grid, we can improve voltage waveform and harmonic components together and simultaneity by using Ultra Capacitor beside DSTATCOM in the system.

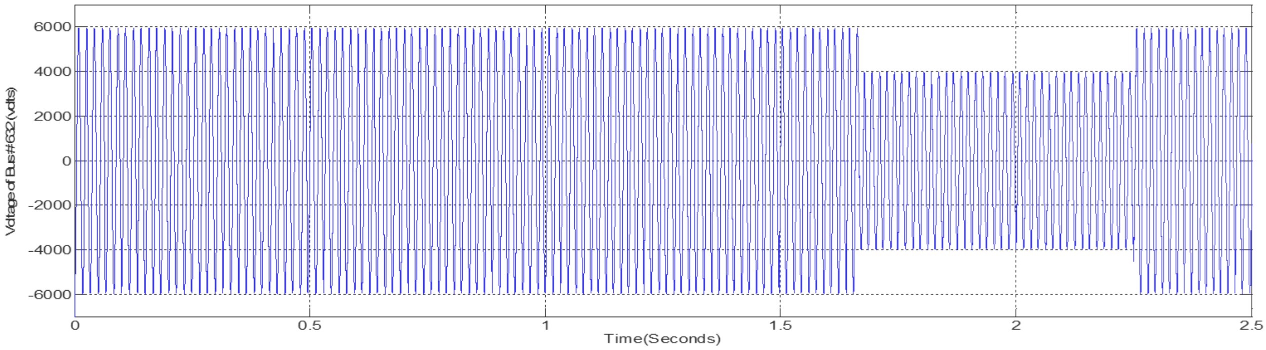

Figure 5. Voltage of bus 632 in presence of Normal Capacitor in system

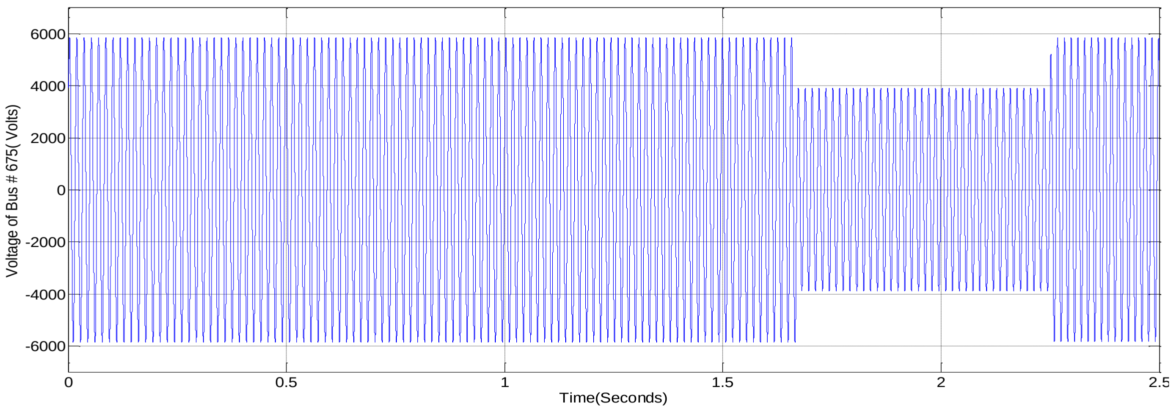

Figure 6. Voltage of bus 675 in presence of Normal Capacitor in the system

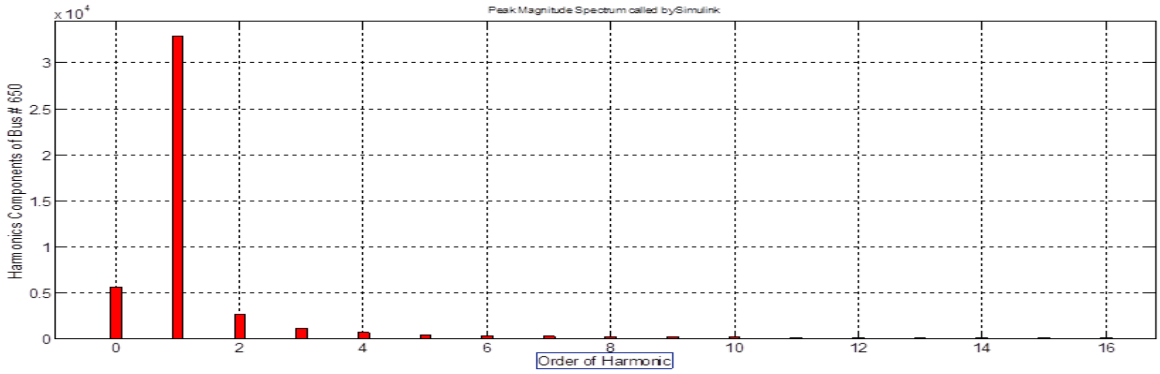

Figure 7. Harmonic components of bus 650 (slack bus) in presence of normal capacitor in the system

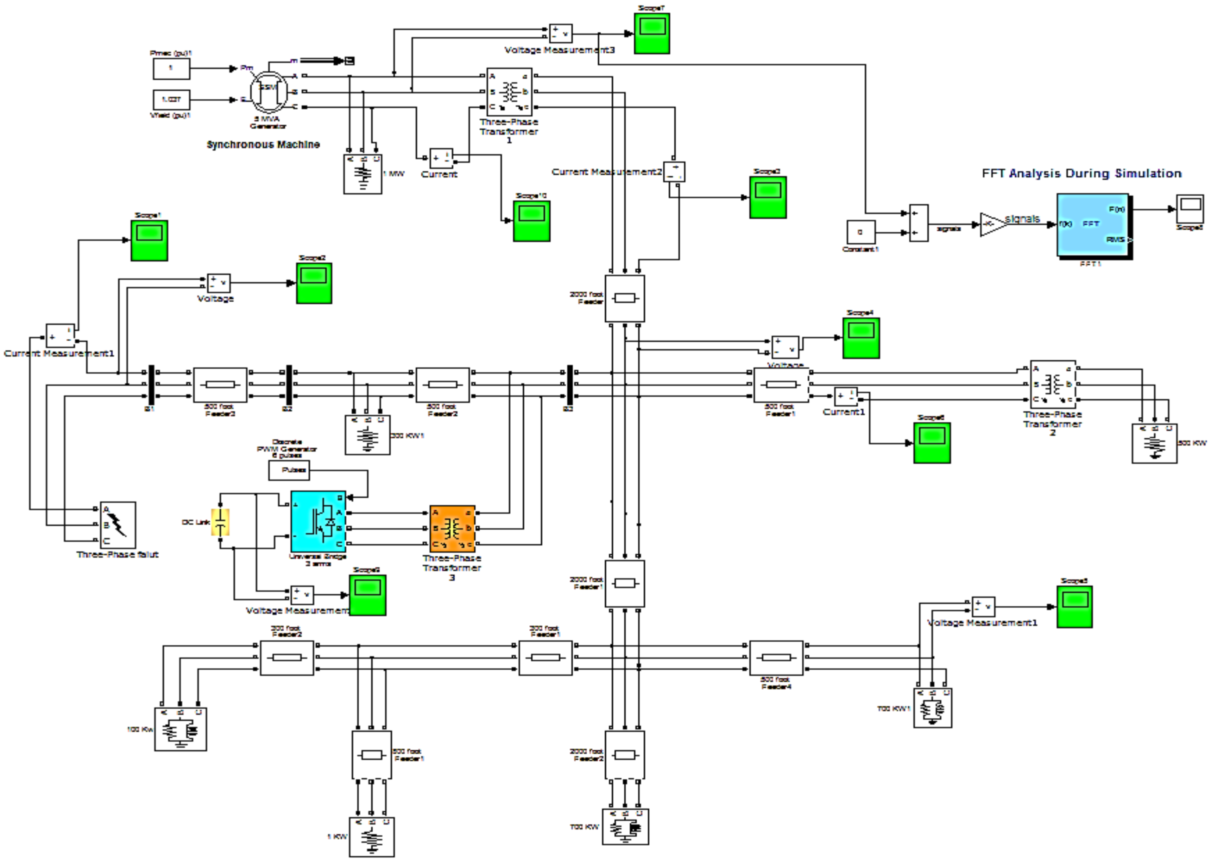

Figure 8. 13-Bus Distribution system, modeled in MATLAB/SIMULINK in presence of UC-DSTATCOM

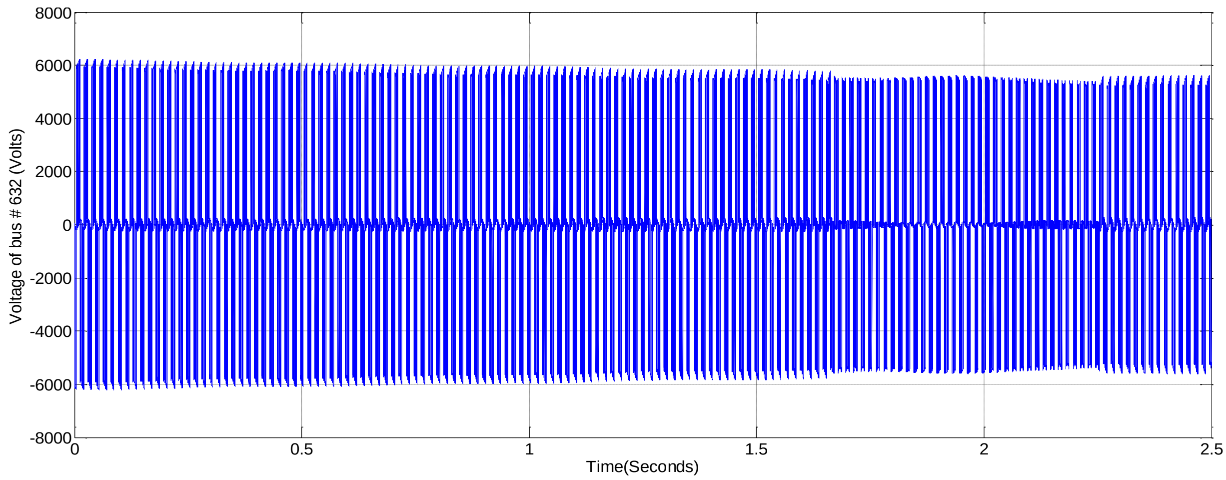

Figure 9. Voltage of bus 632 in presence of UC-DSTATCOM in the system

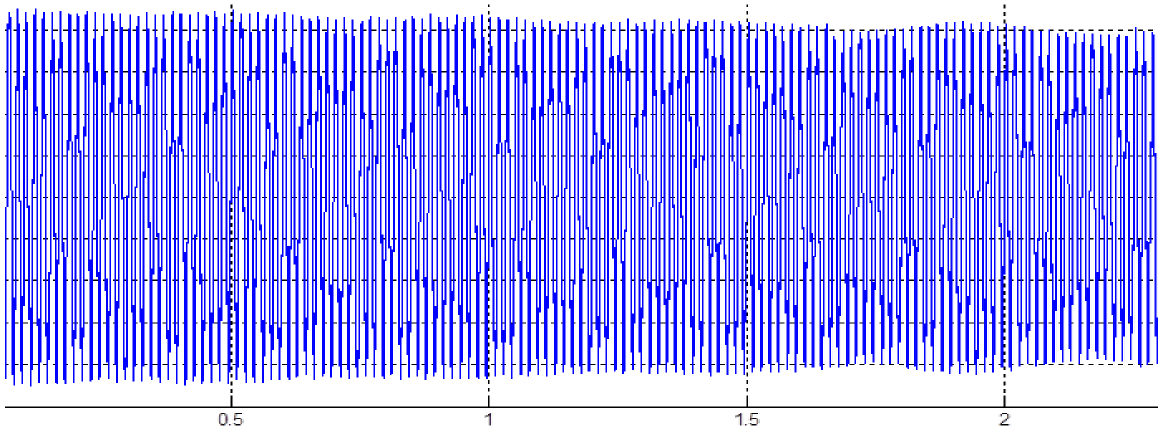

Figure 10. Voltage of bus 675 in presence of UC-DSTATCOM in the system

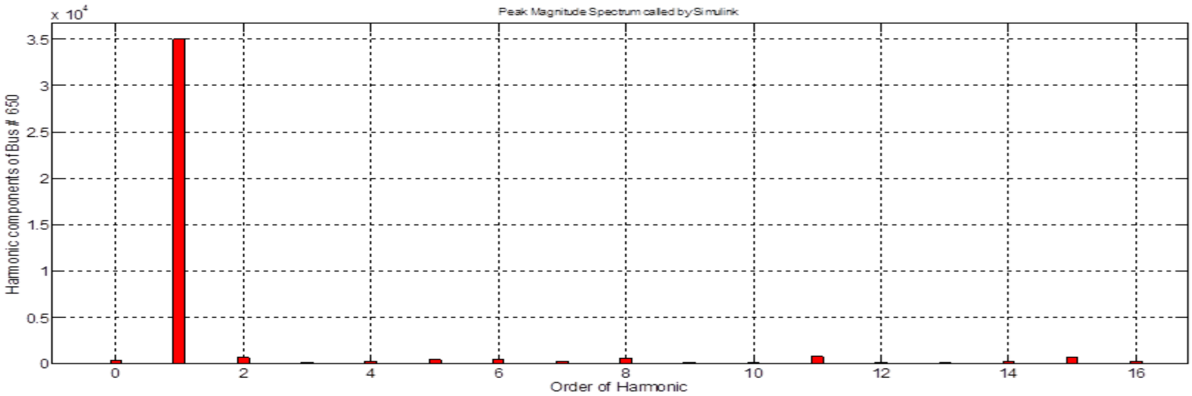

Figure 11. Harmonic components of bus 650 (slack bus) in presence of UC-DSTATCOM in the system

V. CONCLUSIONS

This paper presents a new approach to improve the voltage profile of distribution power system and harmonic components together and simultaneity, against contingencies in the system such as fault occurrence. The proposed addition devices are DSTATCOM and Ultra Capacitor that used commonly in transient problems of the power systems. Then, the aforementioned distribution power system is equipped with DSTATCOM as a suitable FACTS device and UC as a rapid Energy Storage System.

UC in the proposed model is based DSTATCOM. A 13-Bus distribution grid has selected for compared UC and General Capacitor. A three-phase to ground fault simulated on previous distribution grid and the simulation in tow sections performed in MATLAB/ SIMULINK, Firstly in presence of normal capacitor in the system and secondly in presence of UC-DSTATCOM.

Simulated results shows that the voltage sags and harmonic components in presence of UC-DSTATCOM, significantly improved and mainly acceptable in considered buses (bus 632, bus 675 and bus 650) rather than while there is a normal capacitor in the system. Indisputable this proposition will have a direct effect on the Power Quality delivery to customers. Therefore, UC-DSTATCOM is a suitable device for increasing the PQ of the distribution power system.

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BIOGRAPHIES

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