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MODELLING AND ANALYSIS OF OPTIMAL UTILIZATION OF SERIES INVERTER SIZING OF UPQC AND MAXIMUM UTILIZATION OF POWER-ELECTRONIC CONVERTERS

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ABSTRACT: The analysis and optimal utilization of series inverter unified power quality conditioner (UPQC) for simultaneous voltage sag/swell and load reactive power compensation are presented in this paper. The main objective of the series inverter of UPQC is to perform simultaneous 1) voltage sag/swell compensation and 2) load reactive power sharing with the shunt inverter. The active power control approach is used to compensate voltage sag/swell and is integrated with the theory of power angle control (PAC) of UPQC to coordinate the load reactive power between the two inverters. Since the active and reactive powers simultaneously delivered by series inverter, this concept is named as UPQC-S (S stands for complex power). MATLAB/SIMULINK model and its results are presented to analyze the developed concept.

Keywords: Active power filter; power angle control; power quality; reactive power compensation; unified power quality conditioner; voltage sag and swell compensation.

I. INTRODUCTION

The different power quality problem makes extremely vulnerable the modern power distribution system. The current and voltage harmonics issues are increase due to the extensive use of nonlinear loads. Furthermore, the penetration level of renewable energy systems based on solar energy, wind energy, fuel cell, etc., installed at distribution as well as transmission levels is increasing significantly [1]. This integration of renewable energy sources in a power system is further imposing new challenges on the electrical power industry to accommodate these newly emerging distributed generation systems [2]. To maintain the controlled power quality policy, some kind of reimbursement at all the power levels is becoming a common practice [3]. At the distribution level, UPQC is a most attractive solution to compensate several most important power quality problems [4]. The general block diagram representation of a UPQC-based system is shown in Fig. 1. It essentially consists of two voltage source inverters connected back to back using a common dc bus capacitor. This paper deals with a novel concept of optimal utilization of a UPQC.

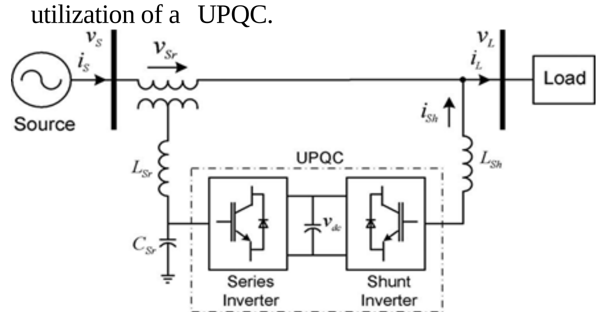

Fig. 1 Unified power quality conditioner (UPQC) system configuration.

The voltage sag/swell on the system is one of the most significant power quality problems [5]. The voltage sag/swell can be effectively remunerated using a dynamic voltage restorer, series active filter, UPQC, etc.. Among the available power quality enhancement devices, the UPQC has better sag/swell compensation capability [6].

Three significant control approach for UPQC can be found to control the sag on the system: 1) Active power control approach in which an in-phase voltage is injected through a series Inverter, popularly known as UPQC-P.

Reactive power control approach in which a quadrature voltage is injected, known as UPQC-Q.

A minimum VA loading approach in which a series voltage is injected at a certain angle, in this paper called as UPQC-VAmin. Among the aforementioned three approaches, the quadrature voltage injection requires a maximum series injection voltage, whereas the in-phase voltage injection requires the minimum voltage injection enormity. In a minimum VA loading come within reach of, the series inverter voltage is injected at an optimal angle with respect to the source current [7]. Besides the series inverter injection, the current drawn by the shunt inverter, to maintain the DC link voltage and the overall power balance in the network, plays an important role in influential the overall UPQC VA loading.

The key contributions of this paper are outlined as follows:

A. The series inverter of UPQC-S is utilized for simultaneous voltage sag/swell compensation and load reactive power compensation in

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coordination with shunt inverter.

B. The available active power, VA loading is utilized to its utmost capacity during all the working situation contrary to UPQC- VAmin.

C. The proposed UPQC-S conception scenario covers voltage sag and swell conditions effectively.

In this paper, PAC mathematical formulation for UPQC-S is carried out. The achievability and usefulness of the proposed UPQC-S approach are validated by simulation results.

II. UNIFIED POWER FLOW CONTROLLER

The UPFC is a combination of a static compensator and static series compensation. It acts as a shunt compensating and a phase shifting device simultaneously.

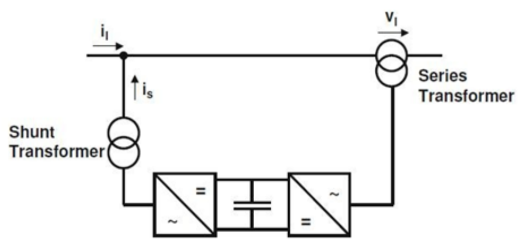

Fig. 2 Principle configuration of an UPFC

The UPFC consists of a shunt and a series transformer, which are associated via two voltage source converters with a common DC- capacitor [8]. The DC circuit allows the active power replace between shunt and series transformer to control the phase shift of the series voltage. [9] This setup, as shown in Fig.2, provides the full controllability for voltage and power flow. The series converter needs to be protected with a Thyristor bridge [10]. Due to the high efforts for the Voltage Source Converters and the protection, an UPFC is getting quite expensive, which restrictions the practical applications where the voltage and power flow control is required simultaneously.

III. OPERATING PRINCIPLE OF UPFC

The basic components of the UPFC are two voltage source inverters (VSIs) sharing a common dc storage capacitor, and connected to the power system through coupling transformers [11]. One VSI is connected to in shunt to the transmission system via a shunt transformer, while the other one is connected in series through a series transformer. The Fig. 3 shows the schematic diagram of basic UPFC functional scheme.

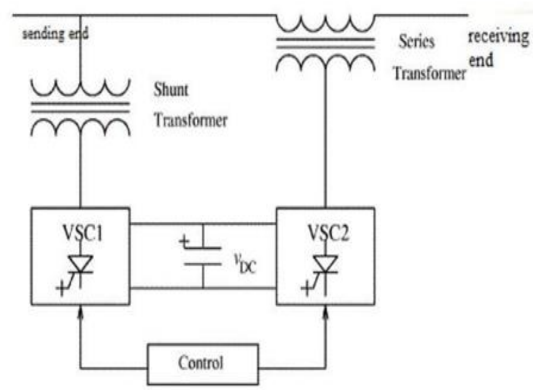

Fig. 3 Functional scheme of UPFC

The series inverter is controlled to inject a symmetrical three-phase voltage system (V_{se}), of controllable magnitude and phase angle in series with the line to control active and reactive power flows on the transmission line. So, this inverter will exchange active and reactive power with the line. The reactive power is electronically provided by the series inverter, and the active power is transmitted to the dc terminals. The shunt inverter is operated in such a way as to demand this dc terminal power (positive or negative) from the line keeping the voltage across the storage capacitor V_{dc} constant [12]. So, the net real power absorbed from the line by the UPFC is equal only to the losses of the inverters and their transformers. The outstanding capacity of the shunt inverter can be used to exchange reactive power with the line so to provide a voltage regulation at the connection point. The two VSI's can work independently of each other by separating the dc side. So in that case, the shunt inverter is operating as an STATCOM that generates or absorbs reactive power to regulate the voltage magnitude at the connection point. Instead, the series inverter is operating as SSSC that generates or absorbs reactive power to regulate the current flow, and hence the power low on the transmission line.

A. Shunt Inverter

The UPFC has many possible operating modes. In particular, the shunt inverter is operating in such a way to inject a controllable current, i_{sh} into the transmission line. The shunt inverter can be controlled in two different modes:

1) VAR Control Mode: The orientation input is an inductive or capacitive VAR request. The

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shunt inverter control translates the VAR reference into a corresponding shunt current request and adjusts gating of the inverter to establish the desired current. For this mode of control a feedback signal representing the dc bus voltage, V_{dc}, is also required.

2) Automatic Voltage Control Mode: The shunt inverter reactive current is without human intervention regulated to maintain the transmission line voltage at the point of connection to a reference value. For this mode of control, voltage feedback signals are obtained from the sending end bus feeding the shunt coupling transformer.

***B.* Series Inverter**

The series inverter controls the magnitude and angle of the voltage injected in series with the line to influence the power flow on the line. The actual value of the injected voltage can be obtained in several ways.

1) Direct Voltage Injection Mode: The reference inputs are directly the enormity and phase angle of the series voltage.
2) Phase Angle Shifter Emulation Mode: The orientation input is phase displacement between the sending end voltage and the receiving end voltage. Line Impedance Emulation mode: The reference input is an impedance value to insert in series with the line impedance
3) Automatic Power Flow Control Mode: The reference inputs are values of P and Q to maintain on the transmission line regardless of system changes.

IV. SIMULATION RESULTS AND DISCUSSION

The performance of the proposed concept of simultaneous load reactive power and voltage sag/swell compensation has been evaluated by simulation as shown in Fig. 4. To analyze the performance of UPQC-S, the source is assumed to be purely sinusoidal. Furthermore, for better visualization of results, the load is considered as highly inductive. The supply voltage which is available at UPQC terminal is considered as three phase, 60 Hz, 600 V (line to line) with the maximum load power demand of 15 kW + j 15kVAR (load power factor angle of 0.707 lag.). The performances of the proposed UPQC-S approach are shown in Fig. 5 and Fig. 6.

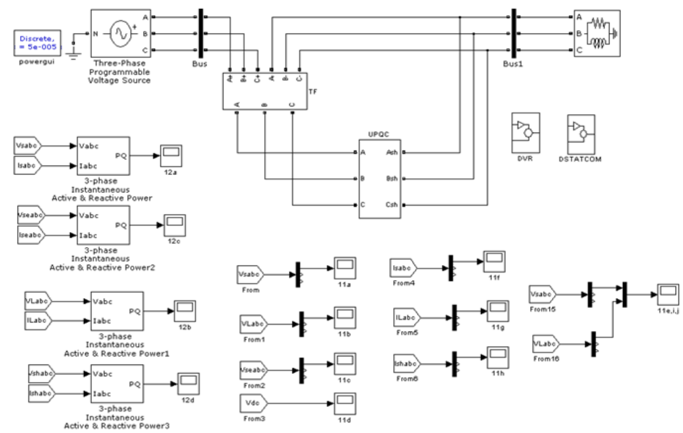
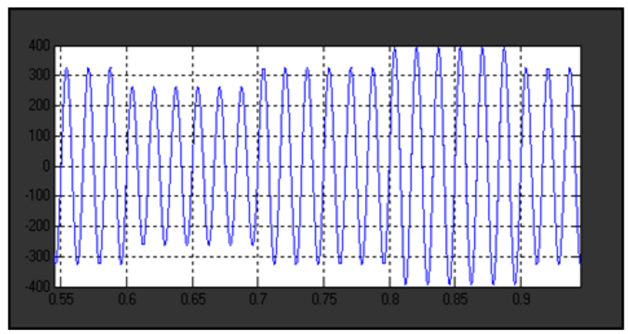
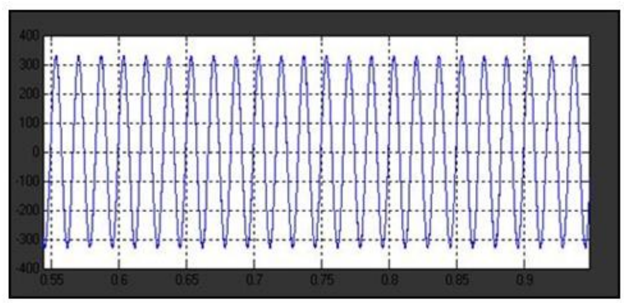


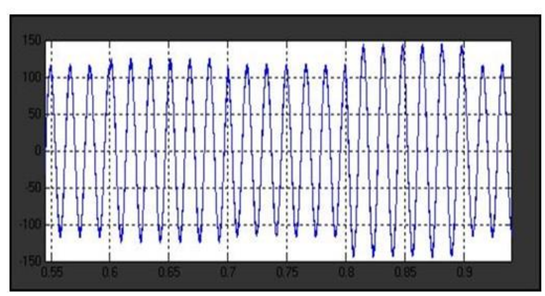
Fig. 4 proposed



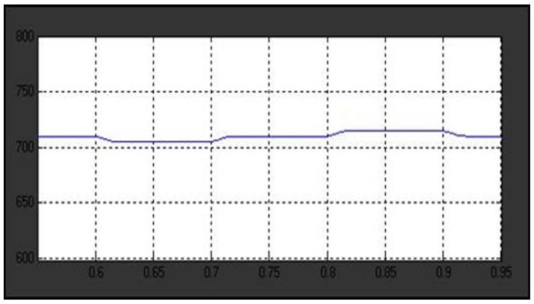
(a) Supply voltage, V_S.



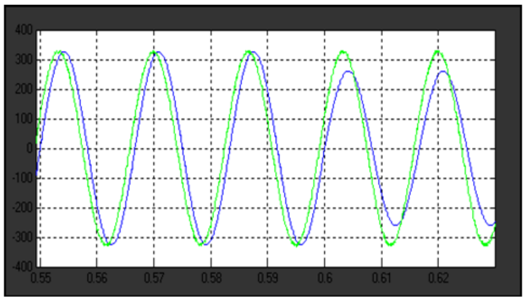
(b) Load voltage, V_L.



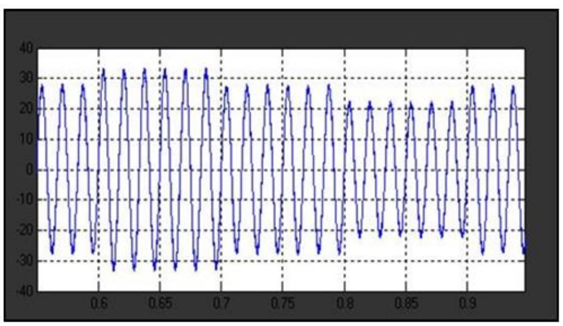
(c) Injected Series inverter voltage.



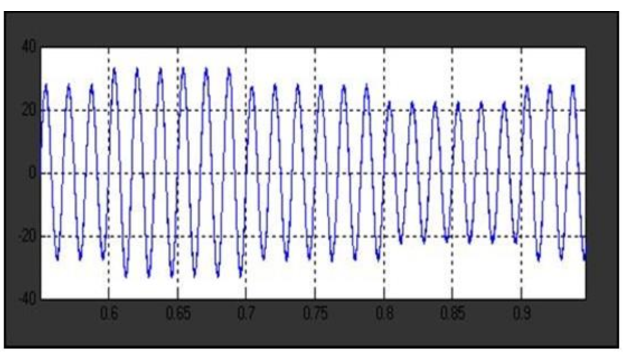
(d) DC bus voltage.



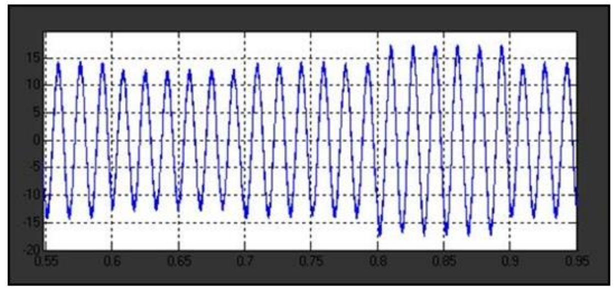
(e) Power angle δ relation between supply and load voltages



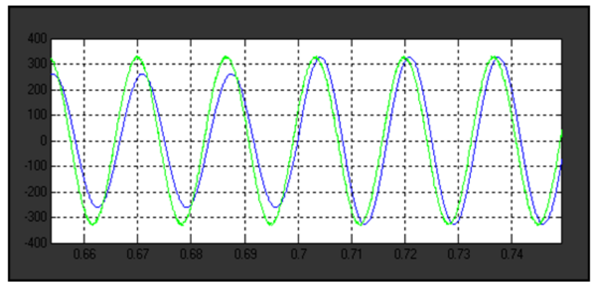
(f) Supply current, I_S.



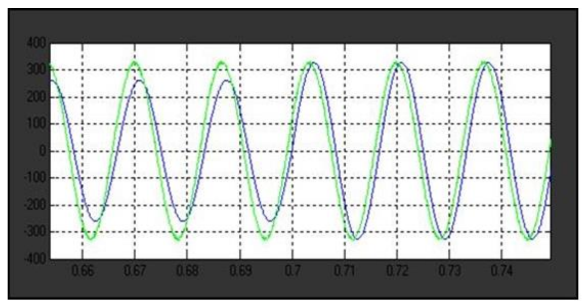
(g) Load current, I_L



(h) Injected Shunt inverter current.



(i) Power angle δ during voltage sag condition



(j) Power angle δ during voltage swell condition.

Fig. 5 (a-j) Performance of the UPQC-S under voltage sag and swell conditions
The system parameters considered for the analysis of proposed UPQC-S are listed in Table 1.

Table I. Parameters of the proposed system

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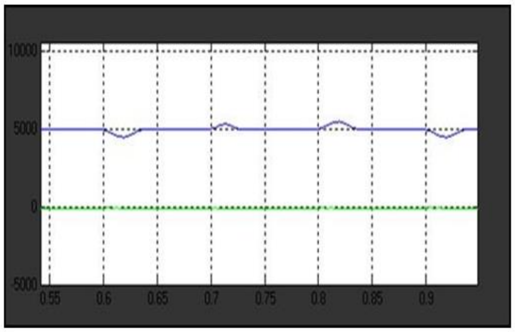
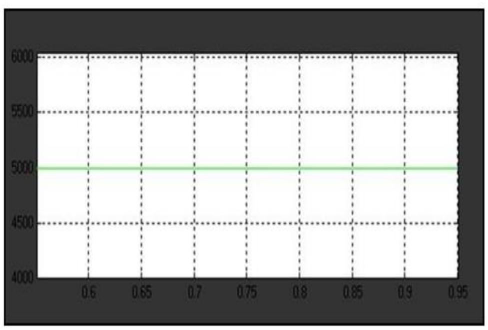
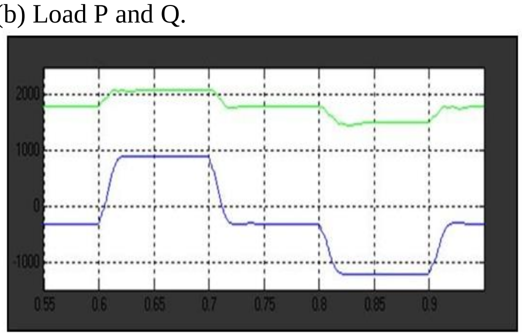
Description	Rating
Three-phase ac supply	= 35 V (rms)
Frequency, f	= 60 Hz
Load	= 40-Ω resistance in parallel with 50-mH inductance
power factor	= 0.6 lagging
dc bus capacitor	= 1100 μF/220 V
reference dc bus voltage	= 150 V
UPQC: shunt inverter coupling inductance	= 5 mH
shunt inverter switching type = analog hysteresis current controller with average switching frequency, f	= between 5 and 7 kHz
series inverter coupling inductance	= 2 mH
series inverter ripple filter capacitance,	= 40 μF
series inverter switching type = analog triangular carrier pulse width modulation with a fixed frequency, f	=5 kHz
series voltage injection transformer turn ratio	=1:3
Sampling time, t_s	=50 μs.



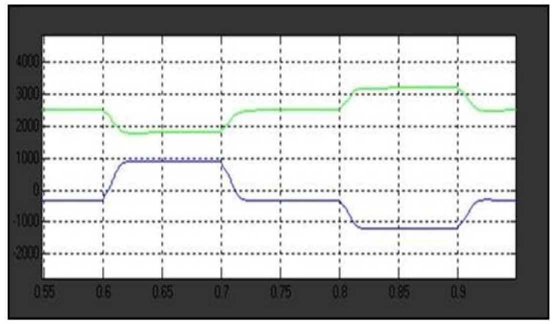
(a) Source P and Q



(b) Load P and Q.



(c) Series inverter P and Q



(d) Shunt inverter P and Q.

Fig. 6(a-d) under voltage sag and swell conditions the active and reactive power flow through the source, load, shunt, and series inverter utilizing proposed UPQC-S

V. CONCLUSION

In this paper, a new concept of controlling complex power (simultaneous active and reactive powers) through a series inverter of UPQC is introduced and named as UPQC-S. The proposed UPQC-S concept is analyzed for voltage sag and swells conditions and formulated mathematically. The developed comprehensive equations for UPQC-S can be utilized to estimate the required series injection voltage and the shunt compensating current profiles (magnitude and phase angle), and the overall VA loading both under voltage sag and swell conditions. The effectiveness of the proposed UPQC-S under simultaneous voltage sag/swell conditions and load reactive power sharing feature are demonstrated in simulation result. The significant advantages of UPQC-S over general UPQC applications are: 1) the multifunction ability of series inverter to compensate voltage variation (sag, swell, etc.) while supporting load reactive power; 2) better utilization of series inverter rating of UPQC; and 3) reduction in the shunt inverter rating due to the reactive power sharing by both the inverters.

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