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# Construction and Performance Investigation of Three Phase Solar PV and Battery Energy Storage System Integrated UPQC

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**Abstract:** *This study examines the use of Unified Power Quality Conditioner (UPQC) to mitigate the power quality problems existed in the grid and the harmonics penetrated by the non-linear loads. The UPQC is supported by the Photovoltaic (PV) and Battery Energy Storage System (BESS) in this work. Generally, the PV system supplies the active power to the load. However, if the PV is unable to supply the power then the BESS activates and provides power especially during the longer-term voltage interruption. The standalone PV-UPQC system is less reliable compared to a hybrid PV-BESS system because of its instability and high environment-dependency. Therefore, BESS will improve the voltage support capability continuously in the longer-term, reduce the complexity of the DC-link voltage regulation algorithm, and keep producing clean energy. The phase synchronization operation of the UPQC controller is directed by a self-tuning filter (STF) integrated with the unit vector generator (UVG) technique. Implementation of STF will make sure the UPQC can successfully operate under unbalanced and distorted grid voltage conditions. Thus, the requirement of a phase-locked loop (PLL) is omitted and the STF-UVG is utilized to produce the synchronization phases for the series and shunt active power filter (APF) compensator in UPQC controller. Finally, the proposed STFUVG method is compared with the conventional synchronous references frame (SRF-PLL) method based UPQC to show the significance of the proposed technique. Several case studies are further considered to validate the study in MATLAB-Simulink software.*

**Keywords:** Battery Energy Storage System (BESS) self-tuning filter (STF) synchronous references frame (SRF-PLL)active power filter (APF) etc.

## I. INTRODUCTION

The UPFC is constructed from two power electronic inverters which are connected together by a common DC link. Two transformers are used to isolate the UPFC and to match the voltage levels between the power system and the power electronic inverters. One of the inverter is connected to the transmission line. The series connected inverter can generate a voltage which can have adjustable magnitude and phase angle. This inverter therefore can provide both real and reactive power to the transmission line. The second inverter primarily provides the real power required by the series inverter but it can also operate as an independent VAR compensator. Therefore the UPFC can control the flow of real and reactive power in the transmission line.

The two VSI's can work independently by separating the DC side. So in that case, the shunt inverter is operating as a STATCOM that generates or absorbs reactive power to regulate the voltage magnitude at the connecting point. The series inverter is operating as SSSC that generates or absorbs reactive power to regulate the current flow, and hence the power flow on the transmission line is regulated.

The UPFC can be used to improve the power quality due to the separate controlling capability of real and reactive power. In this proposed work two bus system is modeled and simulated with UPFC. 14 bus system is also modeled and simulated with and without UPFC. The real and reactive power is investigated and observed that the real power increases with the increase in the angle of injection. The reactive power increases with the shunt voltage injection.

Simulink models are developed for PWM inverter based UPFC, SVM inverter based UPFC and MLI based UPFC. The results of these three cases are compared. Multiple and Distributed Dynamic Voltage Restorer (DVR) concept is introduced to improve the voltage profile of the system.The IEEE 30 bus system is modeled and simulated with and without UPFC. The real and reactive powers are investigated. Voltage sag compensation is done by adding a additional load and it is observed that the UPFC mitigate the voltage sag.

## II. LITERATURE REVIEW

The UPFC, which was proposed by Gyugyi in 1991, is one of the most complex FACTS devices in a power system today. It is primarily used for independent control of real and reactive power in transmission lines for a flexible, reliable and economic operation and loading of power system. Until recently all three parameters that affect real and reactive power flow on the line, i.e. The line impedance, voltage magnitudes at the terminals of the line and power angle, were controlled separately using either mechanical or other FACTS devices such as a Static Var Compensator (SVC), a Thyristor Controlled Series Capacitor(TCSC), a phase shifter etc. However, the UPFC allows simultaneous or independent control of these parameters with transfer from one control scheme to another in real time. Also, the UPFC can be used for voltage support, transient stability improvement and damping of low frequency power oscillations.

UPFC which consists of a series and shunt converter connected by a common DC link capacitor can simultaneously perform the function of transmission line's real and reactive power flow control in addition to bus voltage shunt reactive power control (Schauder et. Al. 1998). The shunt converter of the UPFC controls the UPFC bus voltage/shunt reactive power and the dc link capacitor voltage. The series converter of the UPFC controls the transmission line real/reactive power flows by injecting a series voltage of

Adjustable magnitude and phase angle (Renz et. Al. 1999). The interaction between the series injected voltage and the transmission line current leads to real and reactive power exchange between the series converter and power system. Under steady state conditions, the real power demand of the series converter is supplied by the shunt converter (Mihilac et. Al. 1996). But during transient conditions, the series converter's real power demand is supplied by the DC link capacitor. If the information regarding the series converter's real power demand is not conveyed to the shunt converter control system, it could lead to the collapse of the DC link capacitor voltage, and the subsequent removal of the UPFC from operation. Very little or no attention has been given to the important aspect of co ordination control between the series and the shunt converter control systems (Padiyar et. Al. 1998 and Round et. Al. 1996).

In contrast to real power coordination between the series and shunt converter control system, the control of transmission line reactive power flow leads to excessive voltage excursions of the UPFC bus voltage during reactive power transfers. This is due to the fact that any change in transmission line reactive power flow achieved by adjusting the magnitude/phase angle of the series injected voltage of the UPFC is actually supplied by the shunt converter. The excessive voltage excursion of the UPFC bus voltage is due to the absence of reactive power coordination between the series and the shunt converter control system. This aspect of UPFC control also has not been investigated (Nashiren Mailah et. Al. 2009).

## III.METHODOLOGY OF TORQUE RIPPLE MINIMIZATION FOR BLDC MOTOR

### 3.1 Basic Circuit of UPFC

The Unified Power Flow Controller consists of two switching converters, which in the implementations considered are voltage sources inverters, as illustrated in Figure 3.2. These inverters, labeled "Converter 1" and "Converter 2" in the figure, are operated from a common dc link provided by a dc storage capacitor. This arrangement functions as an ideal ac to ac power converter in which the real power can freely flow in either direction between the ac terminals of the two inverters and each inverter can independently generate or absorb reactive power at its own ac output terminal.

Converter 2 provides the main function of the UPFC by injecting an ac voltage Vpq with controllable magnitude Vpq (0 VpqVpqmax) and phase angle, ($0 \leq \delta \geq 360$ ) at the power frequency, inserted with line via an insertion transformer. This injected voltage can be considered essentially as a synchronous ac voltage source. The transmission line current flows through this voltage source resulting in real and reactive power exchange between it and the ac system. The real power exchanged at the ac terminal ( i.e. at the terminal of the insertion transformer) is converted by the inverter into dc power which appears at the dc link as positive or negative real power demand. The reactive power exchanged at the ac terminal is generated internally by the inverter.

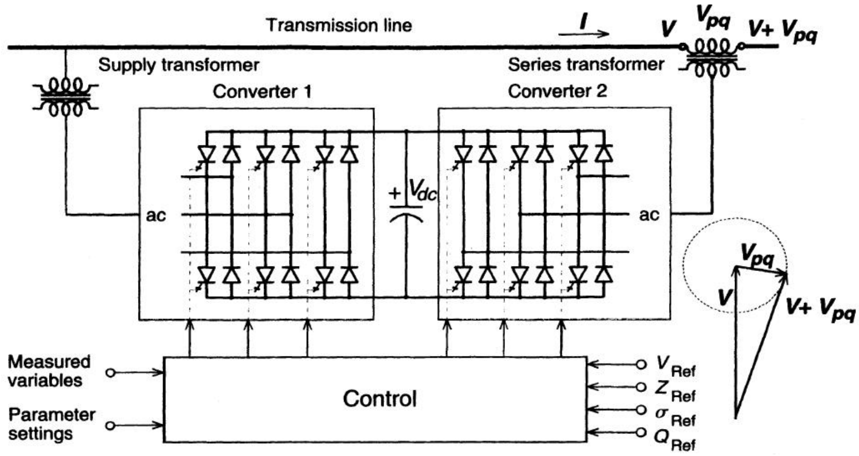


Figure 3.2 UPFC Connected to a Transmission Line

The basic function of Converter 1 is to supply or absorb the real power demanded by Converter 2 at the common dc link. This dc link power is converted back to ac and coupled to the transmission line via a shunt connected transformer. Converter 1 can also generate or absorb controllable reactive power, if it is desired, and thereby it can provide independent shunt reactive compensation for the line. It is important to note that whereas there is a closed “direct” path for the real power negotiated by the action of series voltage injection through Converters 1 and 2 back to the line, the corresponding reactive power exchanged is supplied or absorbed locally by Converter 2 and therefore it does not flow through the line.

Thus, Converter 1 can be operated at a unity power factor or be controlled to have a reactive power exchange with the line independently of the reactive power exchanged by Converter 2. This means that there is no continuous reactive power flow through the UPFC is shown in ( figure. 3.2 )

Procedure leading to the formulation of the state matrix to study the dynamic stability of multi machine power system in the presence of UPFC (Kannan sreenivasachar et. al. 2000). Two different control structure have been evaluated for closed loop stability. The improvement in dynamic stability with the different control structures has been presented for a multi machine multi UPFC power system.

(Toufan and Annakkage 1998) investigates the performance of a UPFC constructed by a back to back connection of a hysteresis current forced converter and a PWM inverter. The UPFC has been modeled at the component level using PSCAD/EMTDC program. The simulation results of the UPFC applications in steady state power flow control and dynamic stability enhancement are demonstrated in a test system.

### 3.2 Control Strategy of UPFC

#### 3.2.1 Shunt Converter Control Strategy

The shunt converter of the UPFC controls the UPFC bus voltage/shuntre active power and the dc link capacitor voltage. In this case, the shunt converter voltage is decomposed into two components. One component is in-phase and the other is quadrature with the UPFC bus voltage. De-coupled control system has been employed to achieve simultaneous control of the UPFC bus voltage and the dc link capacitor voltage.

#### 3.2.2 Series Converter Control Strategy

The series converter of the UPFC provides simultaneous controls of real and reactive power flow in the transmission line. To do so, the series converter injected voltage is decomposed into two components. One component of the series injected voltage is in quadrature-injected component controls the transmission line real power flow. This strategy is similar to that of a phase shifter. The in-phase component controls the transmission line reactive power flow. This strategy is similar to that of a tap changer.

## IV. RESULT ANALYSIS

UPQC DC-link directly, the PV array is constructed in a way such that the maximum power point (MPP) voltage isequivalent to the reference DC-link voltage. During nominal conditions, the rating of PV array ensures that the load

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active power is delivered by the PV array and power is supplied to the grid and charging BESS by the PV array as well. Besides the BESS is designed in a way that, when the PV array generate less power than the DC-link load demand, the BESS provides the insufficient power equivalent to the decrease in DC-link voltage. Moreover, when there is no power produced by PV array, the BESS will supply the total load demand.

### 4.1 Simulation For UPFC

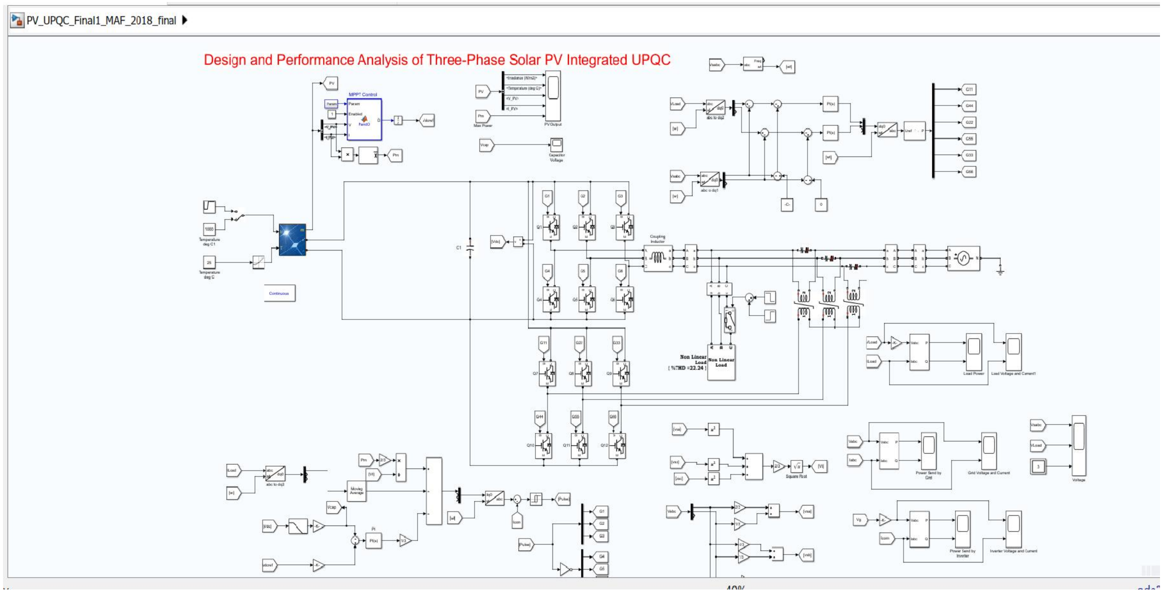


**Fig. 4.1** Matlab Simulation for Three phase inverter integrated FC

The three-phase system is designed for the PV-BESS-UPQC model. The PV-BESS-UPQC comprises of series and shunt APF compensator linked with DC-link split capacitor. The battery and the PV array are linked parallelly to the DC-link. The PV is linked through a boost converter to the DC-link. Moreover, the BESS is linked through a buck-boost converter to the DC-link. The series compensator works likea controlled voltage source manner and mitigates for the supply voltage sags, swells, interruption, voltage harmonic. On the other hand, the shunt compensator mitigates the current harmonics for the load. Both the series and shunt APF compensator are attached through interfacing inductors.as shown in Fig. 4.5 UPQC system configuration Due to the converter switching action harmonics are generated and therefore, ripple filter is utilized to filter out harmonics. The series compensator uses a series injection transformer to insert voltage to the grid. In this work, a threephase non-linear load is utilized. The PV-BESS-UPQC design procedure starts with the accurate measurement of PV array, split capacitor, reference voltage of DC-link etc. The design of the shunt compensator follows the way that apart from mitigating current harmonics it controls the peak output power from PV array. Since the PV array is nnected to the

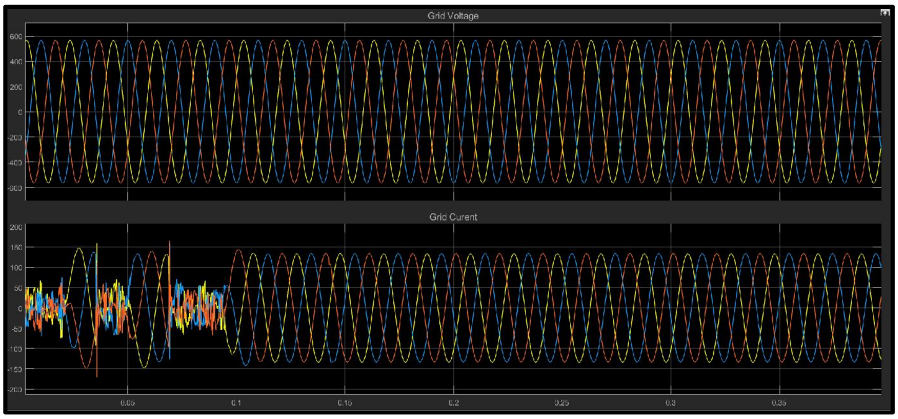


**Fig. 4.2** Three phase Grid Voltage and Grid Current for integrated UPFC

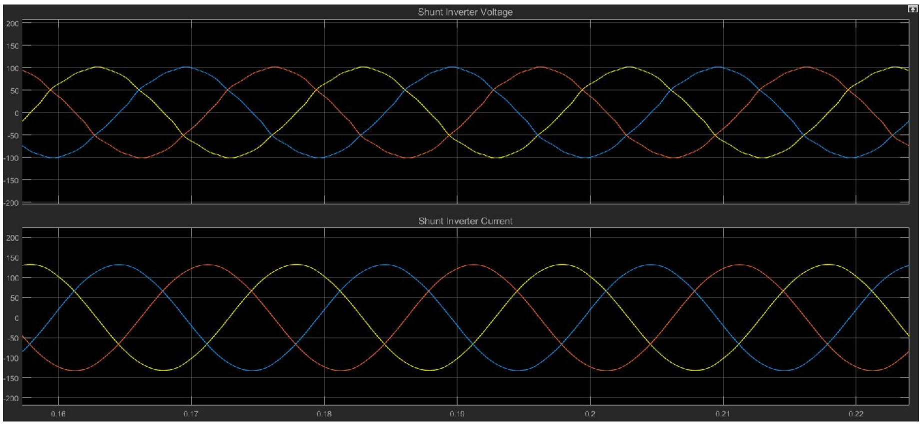


**Fig. 4.3** Three Phase Shunt Inverter Voltage And Shunt Inverter Current For Integrated UPFC

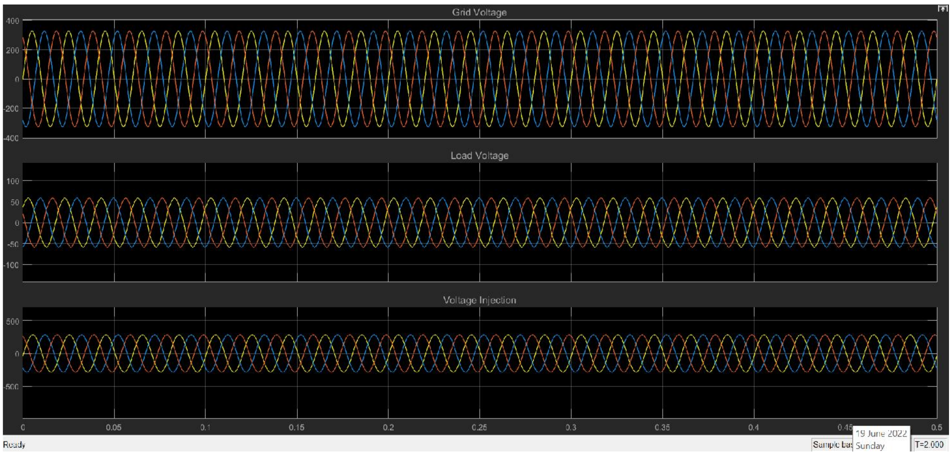


**Fig. 4.4** Comparison between Grid Voltage , Load Voltage,Voltage Injection For Integrated UPFC

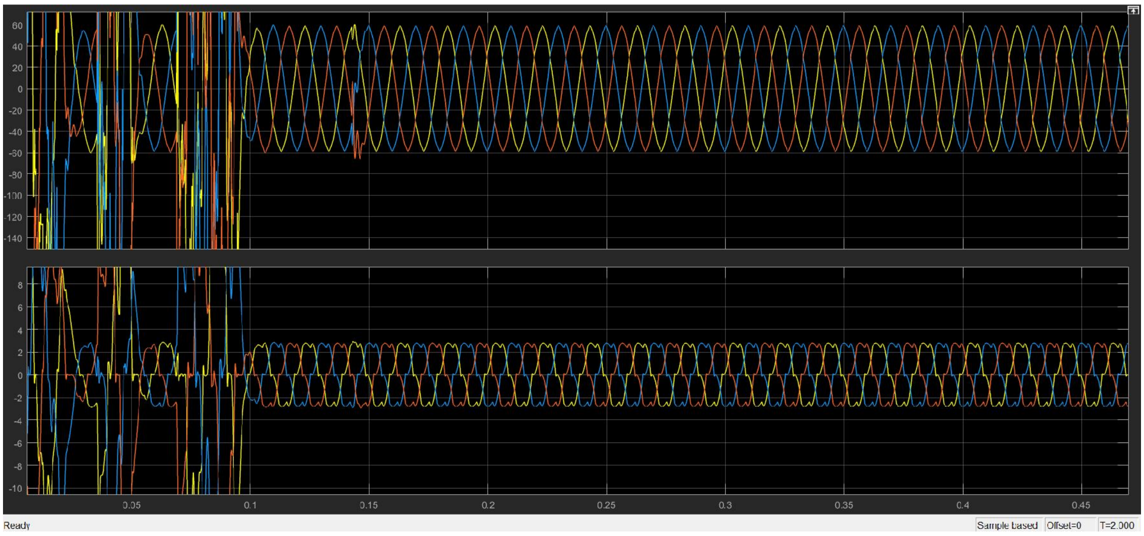

**Fig. 4.5** Load Voltage & Load current before the Inveter integrated UPFC

The results presented are studied on Single Machine Infinite Bus (SMIB) power network which reflects suitability of this approach in tuning UPFC control parameters and also extendable to multi area systems.

- In this model two voltage sources are used to represent the fundamental components of the PWM controlled output voltage waveform of the two branches in the UPFC.
- The impedance of the two coupling transformers is included in the proposed model and the losses of UPFC depicts the voltage source equivalent circuit of UPFC.
- The series injection branches a series injection voltage source and performs the main functions of controlling

power flow whilst the shunt branch is used to provide real power demanded by the series branch and the losses in the UPFC.

## V. CONCLUSION

UPFC based controllers such as POD controller and d-q controller are effectively implemented on the power system to enhance protection. It supports good power compensation results. There is a marked improvement in the real and reactive power flow through the transmission line with UPFC when compared to the system without UPFC. The limitations in long transmission line caused by thermal capability which can be maximized using Unified Power Flow Controller. UPFC enhances the capability of Transmission line and hence the power system.

## VI. FUTURE SCOPE

The problems of system perturbations, oscillations, power swings and stability issues of a power system are such that as the complexity and capacity of a power system increases, these conditions also increase. But these discrepancies occurring in the system can be solved by using UPFC based controllers. UPFC can be effectively installed up to 200 to 300 km of the transmission line length and at the same time making an improvement of up to 15 % to 25 % in the power quality. There is much more scope to study the various controllable parameters of UPFC which can give a further better understanding of UPFC's effect and interaction with the network. Furthermore, UPFC has a lot of scope for developing the future intelligent transmission network (smart grid) equipped with other FACTS devices and state-variable stabilizing controls. The smart grid opportunities and its influence on loss minimization can be thoroughly studied in future.

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