Power Quality Improvement in a Smart Grid Using MPFC

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***Abstract*—This paper presents a switched power filter compensator FACTS device for voltage stabilization, power factor improvement, line loss reduction and power quality enhancement in a long distribution feeder feeding non-linear arc type or temporal inrush type loads. Modulated Power Filter Compensator (MPFC) scheme for the smart grid stabilization and efficient utilization is shown in this paper. The MPFC is controlled by a dynamic tri-loop error driven PID controller. A tri-loop error driven inter coupled PID controller is used to adjust the PWM switching for MPFC. For effective power quality improvement, voltage stabilization, power factor correction and transmission line loss reduction, MATLAB digital simulation models of the proposed MPFC scheme has been fully validated. The proposed FACTS based scheme can be extended to distributed/dispersed renewable energy interface and utilization systems and can be easily modified for other specific stabilization, compensation requirements, voltage regulation and efficient utilization. Different power circuits topologies and control scheme for each type of active power filter are analyzed. The proposed system uses a single-phase PWM converter to control the angle and amplitude of the injection current for each of the firing angle of a three-phase converter. The switching process is achieved by novel dynamic control strategies and the pulse width modulation-complementary switching (PWM). The compensation characteristics of each topology with the respective control scheme are proved by simulation and experimentally. Digital validation is conducted for different cases of load, excursions and fault conditions using the Matlab / Simulink / Sim Power software environment with and without the modulated power filter compensator.**

I. INTRODUCTION

The Application of power electronics devices such as arc furnaces, adjustable speed drives, computer power supplies etc. are some typical non-linear characteristic loads used in most of the industrial applications and are increasing rapidly due to technical improvements of semiconductor devices, digital controller and flexibility in controlling the power usage. These power electronic based loads offer highly non-linear characteristics [10]. The wide use of non-linear loads, such as diode and thyristor rectifiers, consumer electronics, uninterruptable power supplies results in the distorted current waveforms in the electrical distribution systems [7]. Due to their non-linearity characteristics power quality problems will arise. The Power quality problem is defined as any variation in voltage, current or frequency that may lead to an equipment failure or malfunction [9]. The power quality is an essential customer-centralized measure which is greatly affected by the distribution and transmission networks operation. It is required to provide economical and effective technical solutions for both power quality and security issues concerned to the electric grid [6]. The different technical options available to improve power quality, active power filters have proved to be an important alternative to compensate for current and voltage disturbances in power distribution systems [8]. These application use controlled converters as a rectifier or as an inverter. The line currents of the controlled converters have high harmonic currents with respect to PWM converters that use IGBT or MOSFET [4].

The modulation index of the single-phase PWM converter is used to control the amplitude of the third harmonic current. A generalized analysis for a three phase controlled converter with the proposed injection technique is proposed to be used in case of a rectifier or an inverter [3]. The presence of harmonics in the power lines results in greater power losses in distribution, interference problem in communication systems and sometimes, in operation failures of electronic equipment’s, which are more and more sensitive since they include microelectronic control systems, which work with very low energy levels. Because of these problems, the issue of the power quality delivered to the end consumers is more than ever an object of great concern [5]. The presented control system is able to compensating current harmonics, reactive power and current unbalance of nonlinear loads [2]. The proposed scheme proved success in improving the power quality, enhancing power factor, reduce transmission losses and limit transient over voltage and inrush current conditions [10].

II. AC STUDY SYSTEM

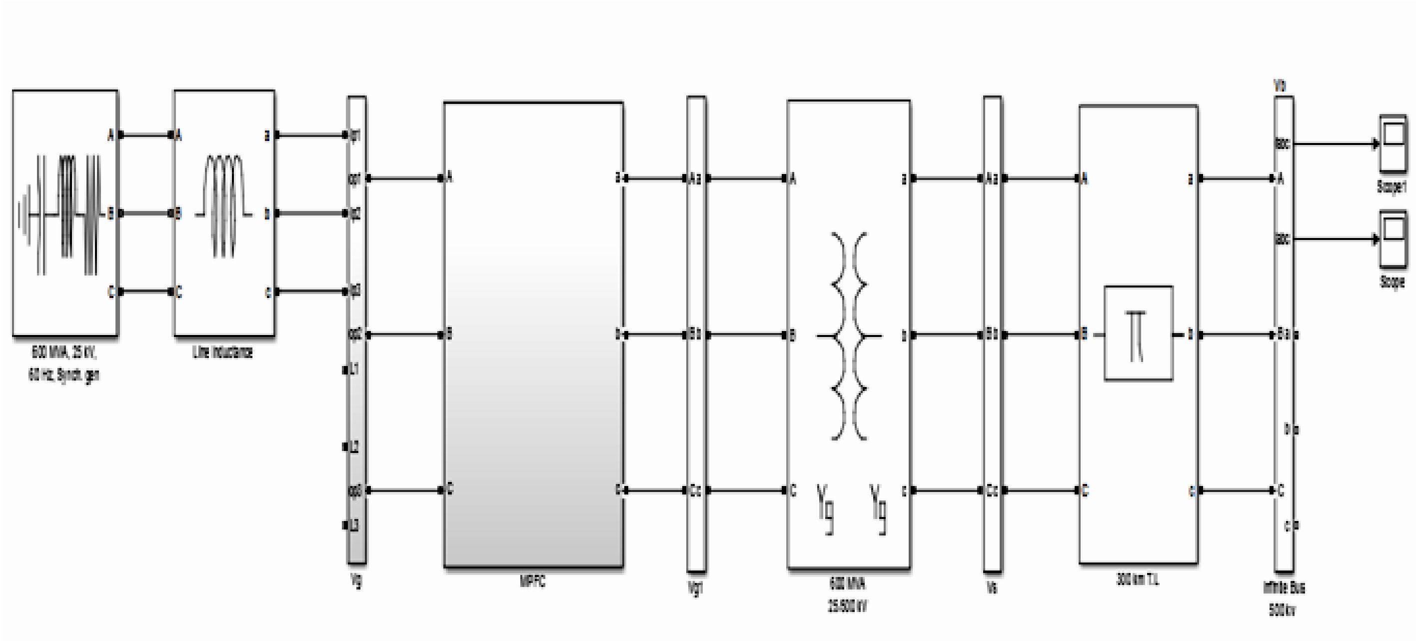


Figure: Single Line Diagram of AC Study System.

The sample study AC grid network is shown in Fig. It comprises a synchronous generator (driven by steam turbine) delivers the power to a local hybrid load (linear, non-linear and induction motor load) and is connected to an infinite bus through 300 km transmission line. The system, compensator and controller parameters are given in the Appendix.

III. METHODOLOGY

1. MODULATED POWER FILTER COMPENSATOR (MPFC)

In order to improve the power quality and power factor correction modulated power filter compensators are used. The modulated power filter compensator is driven by a Tri loop Dynamic Error Driven PI controller, which is a very effective for power quality improvement and power factor correction. Also, modulated power filter compensators can help reducing the total harmonic distortion. Total harmonic distortion (THD) is the summation of all harmonic components of the current or voltage waveform compared against the fundamental component of the current or voltage wave (Is1, Vs1).

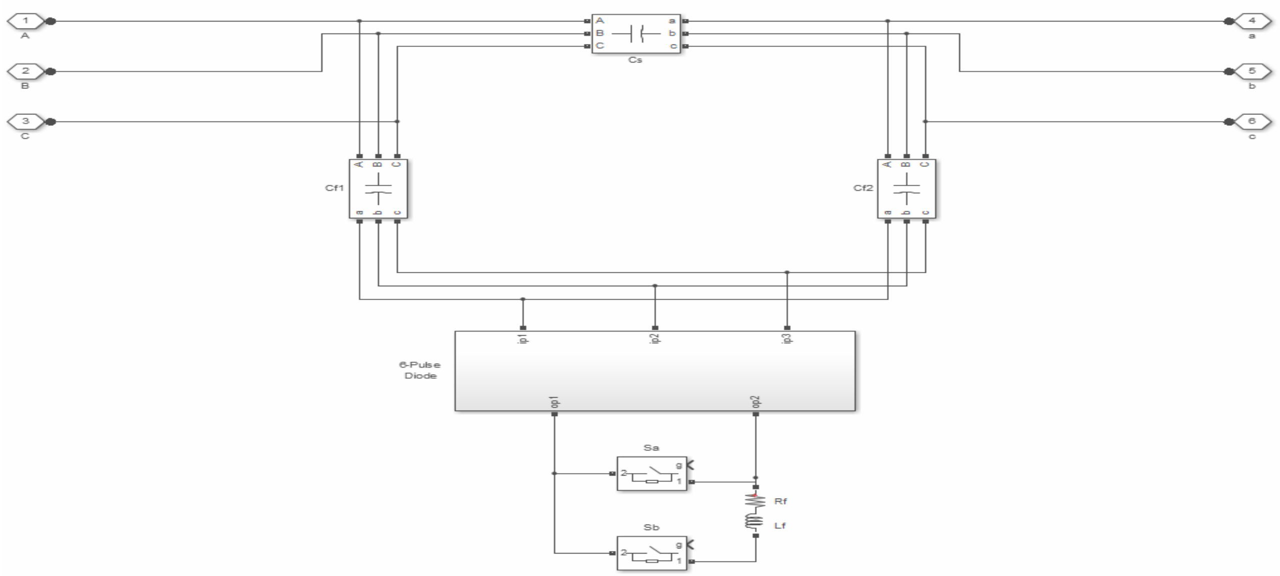


Figure: Modulated Power Filter Compensator

Figure shows the modulated power filter compensators, which is consist of a filter capacitor bank, a filter inductance, a filter resistor, a six-pulse diode rectifier, and two switches. First, in a power electronic system assembles general building blocks:

- AC/DC converters: rectifiers that convert ac to dc with adjustment of voltage and current.

- DC/AC converters: inverters that produce ac of controllable magnitude and frequency, particularly with galvanic isolation via a transformer.
- AC/AC converters: ac frequency, phase, magnitude, and power converters particularly with an intermediary dc link.
- DC/DC converters: linear regulators and switching choppers.

2. **DYNAMIC TRI-LOOP ERROR**

A dynamic tri-loop error driven controller characterized by structural simplicity and a fast, flexible and parameter insensitive feature is applied to adjust the pulsing sequence of the switch 1 and 2 in the modulated power filter compensator. The topology of dynamic tri-loop error driven controller is shown in figure. The dynamic tri-loop error driven controller comprises three basic loops. The tri loop dynamic error driven PID controller is used to generate the required sequence of pulses for a PWM switching device and stabilize the voltage at the load bus by regulating pulse width switching pattern of two complementary switched GTO devices. This controller comprises three basic regulating loops for RMS load voltage, dynamic load current and minimum current-ripple loops. These three weighted and dynamically acting loops play an important role in effective dynamic voltage stabilization and reactive power compensation. The scaling and time delay selection of these key loops is done using an offline guided trial and error method to ensure fast response and minimize the total error.

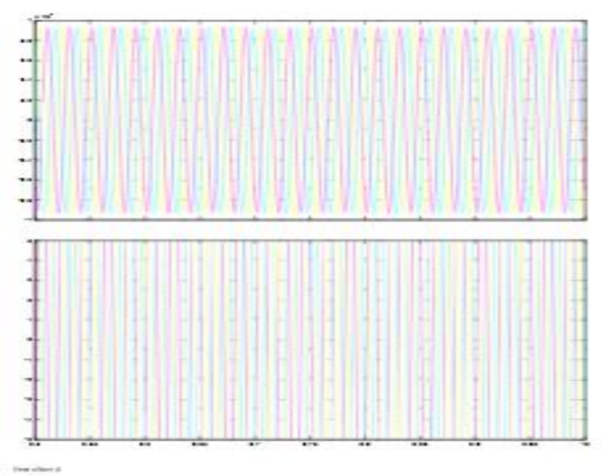
Loop 1– The main loop for the dynamic voltage error using the RMS voltage at the load bus. This loop is to maintain the voltage at the load bus at a reference value by modulating the admittance of the compensator.

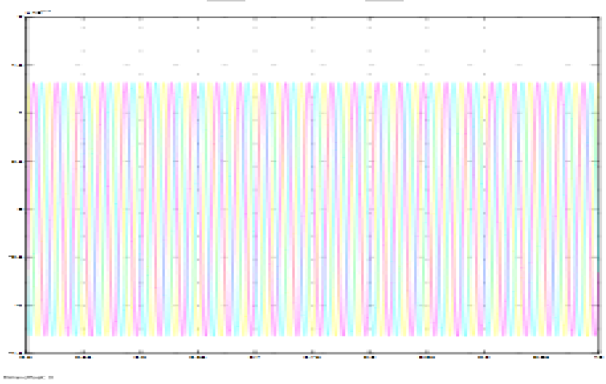
Loop 2 **-** The RMS dynamic load current is used in his loop as an auxiliary signal to compensate for any sudden electrical load excursions.

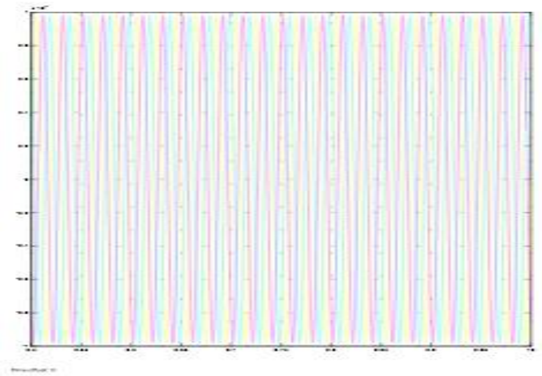
Loop 3**-** The third Current-Ripple loop is added to minimize the total harmonic ripple content in the load current.

IV. SIMULATION RESULTS

Results with MPFC







V. CONCLUSION

This paper presents a novel modulated switched power filter compensator (MPFC) scheme is controlled by a dynamic tri-loop dynamic error driven PID controller. The proposed FACTS based scheme can be extended to other distributed/dispersed renewable energy interface and utilization systems and can be easily modified for other specific compensation requirements, voltage stabilization and efficient utilization. The proposed MPFC scheme has been validated for effective power quality improvement, voltage stabilization, and power factor correction and transmission line loss reduction when the system is extensively simulated in MATLAB/SIMULINK.

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