A Novel Facts Based Improvement of Power Quality

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ABSTRACT—
Modulated power filter compensator (MPFC) scheme for the smart grid stabilization and efficient utilization is shown in this paper. A novel tri-loop dynamic error driven inter coupled modified PID controller is used to control MPFC. For effective power quality (PQ) 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.

Keywords: FACTS, Dynamic Voltage stabilization, Smart Grid, Stabilization, Efficient Utilization.

I. INTRODUCTION:

A power quality problem is defined as any variation in voltage, current or frequency that may lead to an equipment failure or malfunction. In a modern electrical distribution system, there has been a sudden increase of nonlinear loads, such as power supplies, rectifier equipment used in telecommunication networks, domestic appliances, adjustable speed drives, etc. These power-electronic-based loads offer highly nonlinear characteristics. Due to their non-linearity, the loads are simultaneously the major causes and the major victims of power quality problems.

Harmonics, voltage sag/swell and persistent quasi steady state harmonics and dynamic switching excursions can result in electric equipment failure, malfunction, hot neutral, ground potential use, fire and shock hazard in addition to poor power factor and inefficient utilization of electric energy manifested in increase reactive power supply to the hybrid load, poor power factor and severely distorted voltage and current waveforms. To improve the efficiency, capacitors are employed which also leads to the improvement of power factor of the mains.

The paper validated a novel modulated power filter compensator (MPFC) scheme, designed by the First Author, to improve the power quality and utilization in smart grid application. The proposed FACTS based system utilizes the tri-loop dynamic error-driven modified PID controller to control the MPFC. 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.

2. MODIFIED POWER FILTER COMPENSATOR (MPFC)
The low cost modulated dynamic series-shunt power filter and compensator is a switched type filter, used to provide measured filtering in addition to reactive compensation. The modulated power filter and compensator is controlled by the on-off timing sequence of the pulse width modulation (PWM) switching pulses that are generated by the dynamic tri loop error driven dynamic modified PID controller. The modified PID controller is equipped with a supplementary error-sequenced compensation loop for fast effective dynamic response in addition to conventional PID activation.

Fig. 1 Modified Power Filter Compensator structure
This scheme of MPFC structure comprises a series fixed capacitor bank and two shunt fixed capacitor banks are connected to a modulated PWM switched tuned arm filter through six pulse uncontrolled rectifier. The matlab model of this scheme structure is shown in Fig. 1

3. TRI LOOP ERROR DRIVEN MODIFIED PID CONTROLLER

The tri-loop error-driven dynamic controller is a novel dual action control used to modulate the power filter compensator [13, 14]. The global error signal is an input to the modified PID controller to regulate the modulating control signal to the PWM switching block as shown in Figs. 2a & 2b. The modified PID includes an error sequential activation supplementary loop to ensure fast dynamic response and affective damping of large excursion, in addition to conventional PID structure.

Fig. 2a Modified tri loop error driven PID controller

Fig. 2b MATLAB functional model of the Inter-coupled tri loop error driven modified PID controller

Fig. 3 The single line diagram of the unified EHV study AC system
4. AC STUDY SYSTEM
The sample study AC grid network is shown in Fig. 3. 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.

5. DIGITAL SIMULATION RESULTS
The Matlab digital simulation results using MATLAB/SIMULINK/Sim-Power Software Environment for the proposed MPFC scheme under three different study cases are:

5.1. Normal Loading Operation Case:
The dynamic responses of voltage, power factor under normal operation are shown Figs.. The RMS of voltage waveforms of the MPFC are shown in Fig. The modulated tuned power filter switching signals that are generated by the dynamic tri loop error driven dynamic modified PID controller are shown in fig. The stable voltage signal of synchronous generator power system stabilization (PSS) is depicted in . The Transmission line losses are shown in Table I.

Fig 4: The RMS voltage at Generator bus without MPFC
Fig 5: The RMS voltage at Generator bus with MPFC
Fig 6: The RMS voltage at Load bus without MPFC
Fig 7: The RMS voltage at Load bus with MPFC
Fig 8: The power factor at Generator bus without MPFC
Fig 9: The power factor at Generator bus with MPFC
Fig 10: The power factor at Load bus without MPFC
5.2 Short Circuit Fault Condition Case
A three phase short circuit (SC) fault is occurred at bus Vs, as shown in Fig. 3, for a duration of 0.1sec, from t = 0.2 sec to t= 0.3 sec. The RMS of voltage and current waveforms at generator and load buses are depicted in Figs.
5.3. Hybrid Local Load Excursions Case
The real time dynamic responses of the system for a load excursion are obtained for the following time sequences.
At \( t = 0.1 \) sec, linear load is disconnected for a duration of 0.05 sec.
At \( t = 0.2 \) sec, nonlinear load is disconnected for a duration of 0.05 sec.
At \( t = 0.3 \) sec, the induction motor torque is decreased by 50% for a duration 0.05 sec.
At \( t = 0.4 \) sec, the induction motor torque is increased by 50% for a duration 0.05 sec.
The RMS of voltage waveforms at generator and load buses under load excursions are depicted in Figs.
RESULTS

<table>
<thead>
<tr>
<th>Case</th>
<th>Without MPFC</th>
<th>With MPFC</th>
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<tbody>
<tr>
<td>1</td>
<td>P Loss</td>
<td>Q Loss</td>
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<tr>
<td></td>
<td>0.0832</td>
<td>0.1542</td>
</tr>
<tr>
<td></td>
<td>0.001</td>
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</tr>
<tr>
<td>2</td>
<td>0.1954</td>
<td>0.3467</td>
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<tr>
<td></td>
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<td>0.007</td>
</tr>
<tr>
<td>3</td>
<td>0.1018</td>
<td>0.1869</td>
</tr>
<tr>
<td></td>
<td>0.0011</td>
<td>0.0065</td>
</tr>
</tbody>
</table>

Comparing the dynamic response results without and with using the proposed MPFC under three study cases; normal operation, short circuit fault conditions and hybrid load excursion, it is quite apparent that the proposed MPFC enhanced the power quality, improved power factor, compensated the reactive power, stabilized the buses voltage and reduced the transmission line losses.

6. CONCLUSIONS

This paper presents a novel modulated switched power filter compensator (MPFC) scheme. The MPFC is controlled by a dynamic tri-loop dynamic error driven modified PID controller. The digital simulation model of the proposed MPFC scheme has been validated for effective power quality improvement, voltage stabilization, power factor correction and transmission line loss reduction. 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. Topology variations and flexible dynamic control techniques can be utilized in renewable energy smart grid interface.

APPENDIX

1) Steam turbine Pout = 600 MW, speed = 3600 rpm.
2) Synchronous generator 3 phase, 1 pair of poles, Vg = 25 kV (L-L), Sg = 600 MVA, Xd=1.79, Xd'=0.169, Xd"=0.135, Xq=1.71, Xq'=0.228, Xq"=0.2, Xl=0.13.
3) Local Hybrid AC Load (90 MVA) linear load: 30 MVA, 0.85 lag pf, non-linear load: P= 20 kw, Q=22.4 MVAR. induction motor: 3phase, 30 MVA, no of poles=4, Stator resistance and leakage inductance (pu) Rs =0.01965 , Ls=0.0397 Rtator resistance and leakage inductance (pu) Rr = 0.01909, Lr=0.0397 Mutual inductance Lm (pu) =1.354
4) Transmission Line VL-L = 500 kV, 300 km length, R/km=0.01273 Ω, L/km=0.9337 mH
5) Infinte Bus: VL-L = 500 kV
6) MPFC: Cs = 30μF, Cf1 = Cf2 = 125μF, Rf = 0.25Ω and Lf = 3mH
7) Controller gains (figure 2): γvg=1, γig=0.5, γpg=0.25, γvg- rip=1, γig-rip=1, γpg-rip=0.5, Ke=0.1, kp=10, ki=5, kd=0.5 and PWM frequency fs=1750 Hz.

REFERENCES

[8] M. Rastogi, N. Mohan, and


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