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STATCOM Control Reconfiguration Technique for Steady State and Dynamic Performance Optimization during Network Fault Conditions

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Abstract: The introduction of flexible AC transmission/distribution system (FACTS) in a power system is to improve the stability, reduce the losses, and also improve the loadability of the network system. Herein, the proposed work is a non-traditional optimization technique which has been adopted to optimize the various process control parameters that contribute notably to control STATCOM device operations in a power system network during any undesired condition. The simulation was performed by taking into consideration STATCOM process control parameters; hereby the controller was also configured in strategic ways to optimize the control model under both steady state and dynamic performances. The optimization process results have clearly indicated that the introduction of STATCOM device in the right location of the system increases the loadability and sustainability of the power system through optimization process. The new control can thus be effectively used for this type of optimization process.

Keywords: *UPFC, TPSC, PSCAD, PLL, PI*

1. Introduction

The generating and absorbing of controllable reactive power with various power electronic switching converters are extensively used in power system to maintain steady state and dynamic performance of the controllers. The use of power electronics has been largely recognized [1-7]. The STATCOM based on voltage source converter is used for voltage regulation in transmission and distribution systems [1-15]. The STATCOM objective is to rapidly supply dynamically defined VARs to meet system operational requirements for voltage support during any system fault condition.

To improve the power electronics based control system performance PWM (plus-width-modulation) strategic operations technique has been developed and adopted through PI controller to reduce the STATCOM and total system losses. The voltage source converters will function precisely and within control limit when the PWM operations technique is in place. In this paper, the PI controller has been used to optimize the "PWM" strategic operations to control the STATCOM process parameters to prevent any possible deviation which may lead to STATCOM tripping. In this connection, suitable DC capacitor selection has been carefully selected so as to enhance its effectiveness to mitigate any possible affects during any abnormal event.

2. Simulated Model Parameters

Figure 1 illustrates the model AC system under normal operations, its limitations as well as STATCOM operations and its limitations in turn.. From an operations point of view, it is also shown in the model as to how the STATCOM will contribute to overcome the situation during repeated fault condition. In figure 2 ,all PI controller parameters have been reconfigured and defined to maintain system transient stability as a priority. Herein, the Qatar Power and Electricity operating parameters have been used to develop a model as listed below.

a) Load
Power = 100MVA
Power factor = 0.908

b) 6th pulse STATCOM
Voltage control with PI controller
PWM carrier frequency with 9 time fundamental and varying DC voltage.

c) AC system
Voltage =115KV
Short circuit =180MVA
Without Voltage control device
normal voltage =0.98 pu
fault condition = 0.82 pu

d) Voltage Control Loop
Measured reactive Power Vs. rated reactive power 300MVAR
Measured voltage Vs. change in voltage o.1 pu
3% drop calculation
30 degree shift due to y-delta transformer
PI values are not optional

e) Fault
Three phase fault to ground with impedance 75 ohms x/r ratio equal to 1
Occurs at 1.5 sec and lasts at 0.75 sec
Transformer step-up
Y/D (100 MVA)

115 KV Y-Section connected with line voltage
25KV Delta-Section connected with STATCOM

f) Filters
90Hz low pass
120Hz notch
60Hz notch

Table I. Simulated Model Abbreviations

symbol	Description
Qm	Reactive Power measured value
MVar	Rated reactive Power
V-pu	AC system Line voltage
v-pu	Reference voltage
Ia,Ib,Ic	Current from the STATCOM
Vna,Vnb,Vnc	Transformer Y side voltage
Vsa,Vsb,Vsc	Transformer Δ side voltage
IaL,IbL,IcL	AC system line current
dcVlt	STATCOM DC voltage
dcCprt	DC capacitor value
PLL	Phase lock loop
PiLL	Loop integral gain
PpLL	Loop proportional gain
Vref	Control loop reference voltage
Verr	Control loop error voltage
PI	Proportional and Integral control
P	Proportional Gain in dB
I	Integral time in sec

3. Operational Principles of FACTS Devices

In the interconnected electrical power system network, it has been ascertained that the resistance of the transmission line is much smaller compared to the reactance and the power flow obeys the kerchoff's law. The active power transmitted by a line between the buses i and j can be estimated by the following relationship:

$$Pij = \frac{Vi\ Vj}{Xij} \sin\delta ij. \qquad (1)$$

Where: Vi and Vj are voltages at buses i and j; Xij: reactance of the line; δij: angle between the Vi and Vj.

The following assumptions are made:-

1) Under the steady state operating condition for high voltage line the voltage Vi =Vj and θij is small.
2) Under the dynamic operating condition for high voltage line, the voltage Vi ≠Vj and θij is variable.
3) The active power flow is coupled with θij and reactive power flow is linked with difference between the Vi-Vj. The control of Xij acts on both active and reactive power flows.
4) STATCOM device has been chosen and located optimally in order to control the power flows in the power system network.

In order to understand FACTS device operations, the following four different typical FACTS devices have been selected: TCSC, TCPAR, SVC and the UPFC. Their block diagrams are shown in Fig 3. These FACTS devices can be applied to control the power flow by changing the parameters of power systems, so that the power flow can be optimized with a certain degree of precision.[8]

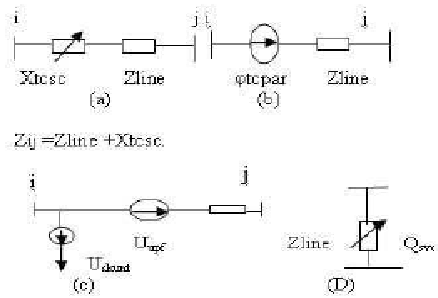

Fig. 3. Block diagram of the FACTS devices:
a) TCSC b) TCPST c) UPFC d) SVC

4. Transformer Behavior During STATCOM Operations

The B-H curve has been measured at point (Ia,Ib,Ic) at the transformer coupling with STATCOM which is also referred in figure 4 during STATCOM operations to analyze the transformer performance. When the transformer flux is smaller than 1.2 pu, the respective magnetizing current increases slowly as the flux reaches 1.25 pu. Subsequently, the magnetizing current will also rise evidently with very low "slope" due to transformer saturation point.

For instance, a the single-line to ground fault on phase "A" indicate a dip in bus "A" voltage; at the same time, other two phase voltages rise as compared to normal case, which may also lead to saturation and large magnetizing currents in phases B and C. As a result, the voltage source converter will reach its high limit of over-current and the STATCOM'S trip will also occur. Further research work is recommended to eliminate such operational conditions with high degree of precision.[17]

Transformer Characteristic

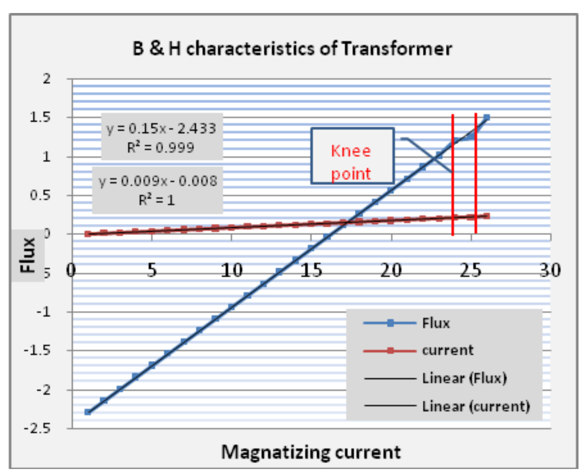

Fig. 4. Transformer Magnetizing current Vs. Flux

5. STATCOM PI (proportional-Integral)

A. Internal control:

PI controller generates a gated command to operate the converters to compensate the error, which has been calculated by comparing defined values against measured values for both reactive and real powers. This is an integral part of the converters.

- PI controller generates a gated command to operate the converters to produce the fundamental voltage waveform to compensate the voltage magnitude as well as to synchronize with the AC system.
- The internal control also takes preventive measures to limit the maximum voltage and current from the individual power converter to maintain safe operations under any system contingency.
- The internal control scheme is only operating the converters with DC power supply or energy storage (static synchronous generator).

B. External control:

- From the field Qm (refer to Table No.1), the measured value is introduced into the PI controller to calculate against the referenced reactive power value and to generate response ± error signal. The error signal will be sent to operate the converter to deliver or absorb required reactive power to eliminate deviation.
- From the field V-pu (refer to Table No. 1), the measured value is introduced into the PI controller to calculate against the reference voltage value and to generate response ± error signal. The error signal will be sent to operate the converter to deliver or absorb the required reactive power to maintain voltage pressure and phase angle.

C. Findings:

- From the internal control, sinusoidal and synchronous voltage can be controlled to draw inductive or capacitive current up to the maximum values, based on its MVA rating.
- The reactive output current is controlled by controlling the DC capacitor voltage indirectly (by the angle of the output voltage) to optimize the reactive output current.
- If the system voltage is depressed from its nominal voltage, maximum reactive current can still be maintained through the system.
- External reactive current reference determines the compensation requirements and internal real current derived from the DC voltage control loop so as to optimize the operations.
- The reactive and real current amplification will generate error signal(s), which will be converted into magnitude and angle of the converter output voltage.

6. Steady State STATCOM Model Performance

In the steady state control model, the STATCOM output voltage waveform is generated electromagnetically, combining eight square wave outputs per phase, which in turn, generates a 48-pulse. The current drawn from the STATCOM is free of harmonics. Figures 5 and 6 show results before and after the PI controller insertion in the steady state STATCOM Model. Although the residual harmonics manifest themselves into the STATCOM output voltage, they are significantly attenuated by the leakage of the inductance of the transformer.

An extensive series of studies have clearly shown that the STATCOM is very effective in maintaining bus voltage at the requisite 115KV level. Essentially, this STATCOM achieves the voltage regulation by either operating in full capacitive or inductive mode of operations according to the system requirements. To compensate network vulnerability, 300 MVar capacitor bank has also been ingrated into the model through careful selection and section processes for effective contribution in the system.

Current drawn after the PI configuration

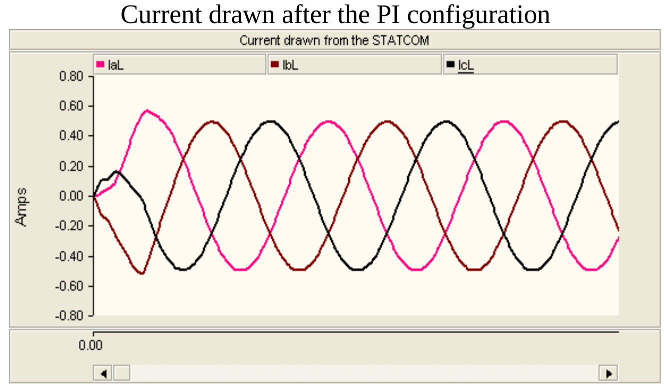

Fig.5. Current drawn from the STATCOM free of harmonic

Current drawn before the PI configuration

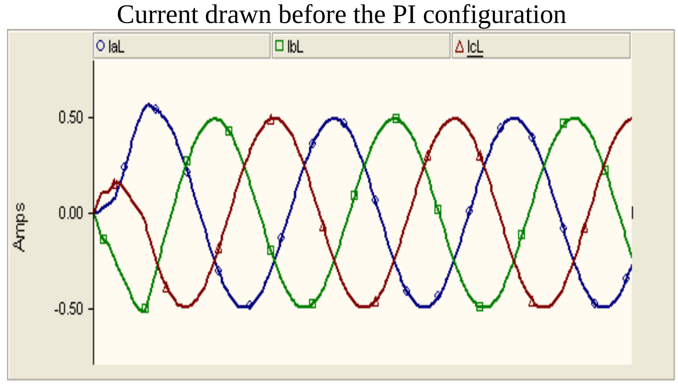

Fig.6. Current drawn from the STATCOM with harmonic

7. Dynamic Model Performance

A. Operating and control Data before Fault:

- Reactive Power: 116.91 MVAR/0.80 Sec
- Real power : -0.32kv/0.80 sec
- Dc-voltage : 33.96 KV/ 0.80 sec
- Line voltage: 0.98 p.u / 0.80 sec reference voltage: 1.00 pu
- Voltage error: 0.02/ 0.80 sec

- Angle order: 0.23 deg/ 0.80 sec

B. *Operating and Control Data after Fault:*

- Reactive Power: this will compensate during fault 363 MVAR at 0.89 sec (compensation time 0.09 sec)
- Real power : this will compensate during fault 14.22 MW and will stepped down -14.31 MW with in 0.83 sec)
- Dc-voltage will drop 38.92 KV at 0.81 sec, which will stepped up to 58.45 MW at 1.20 sec and stepped down 4.58 at 1.26 second
- Line voltage: 0.98 p.u / 0.80 sec reference voltage: 1.00 pu
- Voltage error: 0.02/ 0.80 sec
- Angle order: 0.23 deg/ 0.80

8. Dynamic Model Observation

The STATCOM has shown an excellent performance in terms of response and settling times when operating in the dynamic mode. To measure the response time of the model, it has been engaged for 3.00 sec to analyze its performance by introducing fault for 0.40 sec and repeated after 0.80 sec. In this regard the STATCOM is very effective to meet the operational requirements by adaptively adjusting its control parameters. The rapid response of the STATCOM due to very small transport delays for controlling the 48-pulse converters has also been clearly demonstrated, which in turn will enable a very high bandwidth to be achieved to control the current.

1) Figure 7 illustrates the real power variation from (-30 to 25 MW) during the repeated fault condition. IThis was measured near the AC system STATCOM transformer coupling.
2) Figure 8 illustrates the DC capacitor voltage variation (30-60KV) during the repeated fault condition. This was measured across the STATCOM capacitor.
3) Figure 9 illustrates the reactive power compensation (50-355 MVAR) during the repeated fault condition. This was measured near the AC system STATCOM transformer coupling.
4) Figure 10 illustrates the variation of angle order from (-15 to 15) degree during the repeated fault condition. This was measured after 30 degree phase-shift of (Y-Δ) transfer in the control loop.
5) Figure11 illustrates the voltage error during the repeated fault condition. This was measure from the control loop by comparing measured voltage deviation against reference voltage during fault condition.
6) Figure 12 illustrates how much line voltage was deviated during the fault condition. This was also measured from the control loop by comparing define voltage (1.5 pu) against voltage deviation during fault condition.

Real Power flow in MW

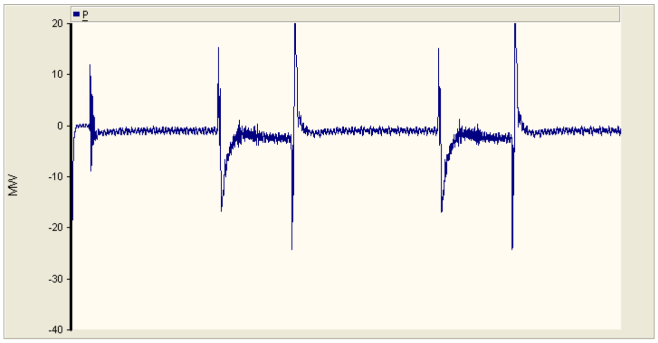

Fig.7. Real power compensation during fault conditions

DC Capacitor Voltage in KV

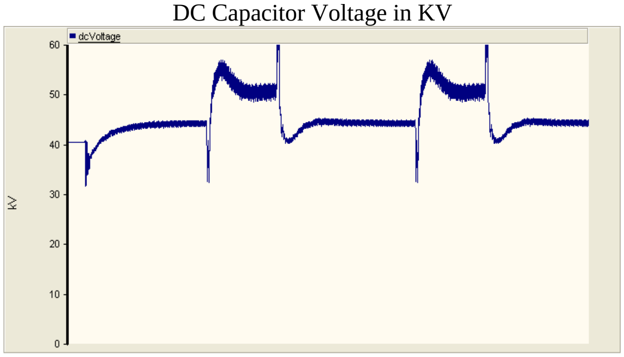

Fig. 8. DC power compensation during fault conditions

Reactive power compensation in MVar

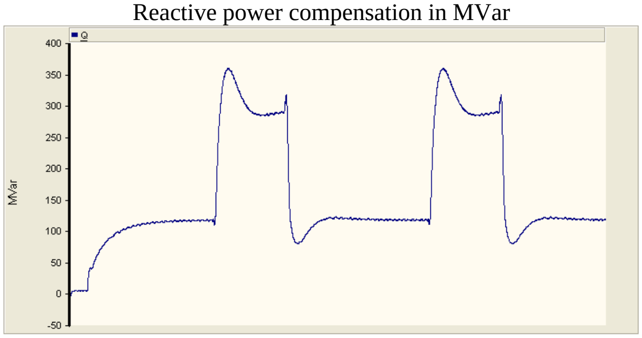

Fig. 8. Reactive power compensation during fault conditions

Angle controlled through PI

Fig. 10. Angle order compensation during fault

Voltage error) during fault condition

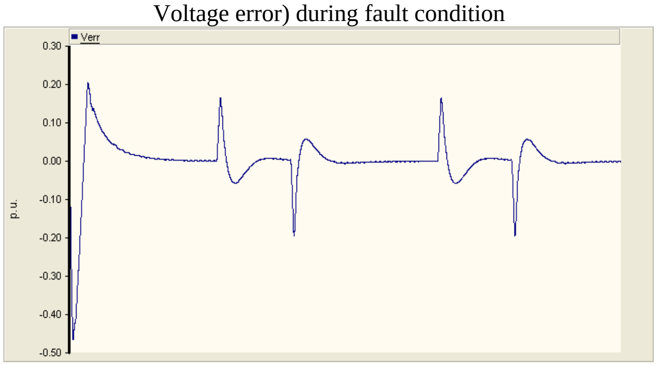

Fig11. voltage error determined during fault

Line voltage variation during fault

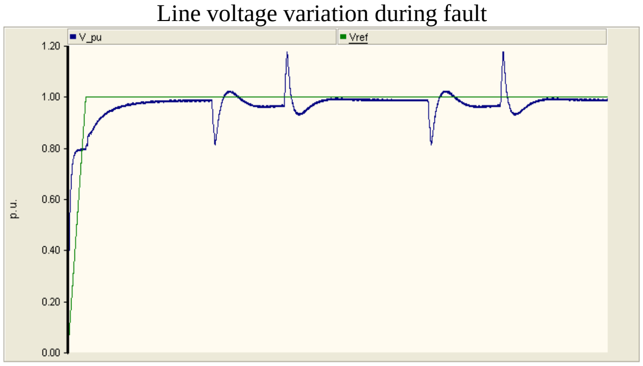

Fig.12. voltage Pu values and Vs reference voltage

9. Results

In the first scenario angle control block gain was adjusted at 45dB (refer to Table No.1) and the reactive power compensation was determined (380-73) MVar during fault condition for 0.40 sec. In the second scenario the angle control gain was increased from 45dB to 65dB (refer to Table No.1) and the reactive power compensation was determined (354-89) MVArs during fault period. In the third scenario, the angle control gain was reduced from 65dB to 58dB to deliver reactive power compensation (361-84) MVArs during the fault conditions. During these three scenarios, the voltage drop was kept constant at 30% and 30 degree shift due to Y-D transformer, respectively.

10. Conclusion

In conclusion, various approaches have been developed and considered to optimize STATCOM operations and its possible contingencies, which occur due to over current and other factors such as under voltage etc. The tripping issue has been addressed to overcome the over-current situation by adjusting to optimize controller gain to limit its control-cycle. The impact of PI control-loop at various gain values in STATCOM operations to supply required reactive power under single-line to ground fault, three-phase fault and line-to-line fault conditions are investigated. It is clearly demonstrated that the defined STATCOM is very effective in maintaining system voltages at requisite level without any constraint.

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STATCOM Model Coupled With Power Source

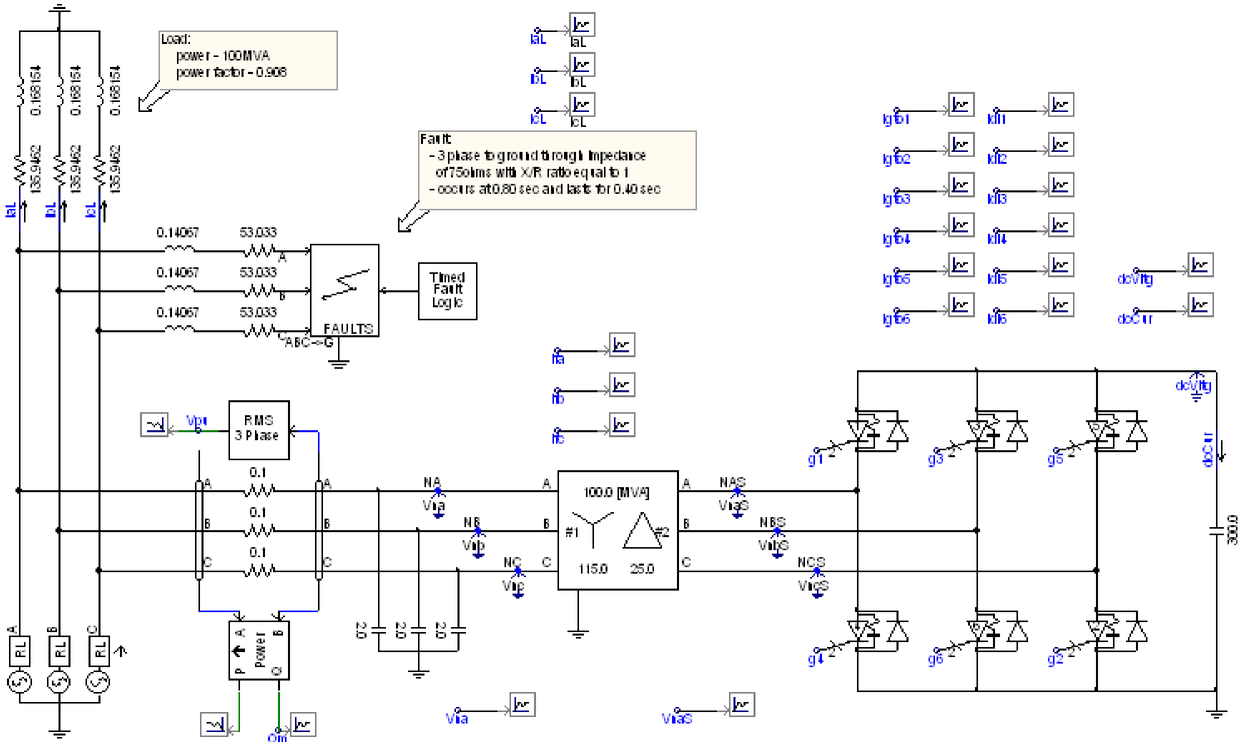

Fig. 1. STATCOM coupled with AC system

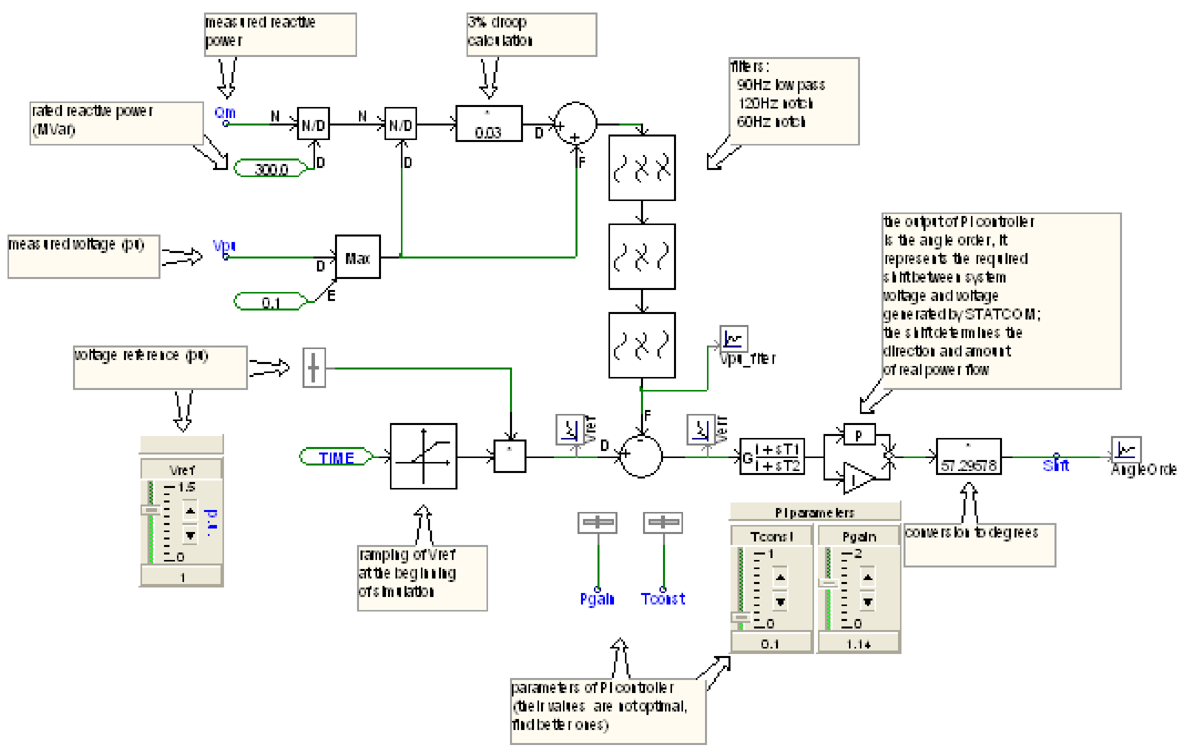

Fig. 2. STATCOM PI contoller configuration coupled with AC system