ACTIVE SUBSTATION DESIGN TO MAXIMIZE DG POWER PENETRATION IN WEAK NETWORKS

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Abstract— The massive integration of distributed generation (DG) can cause voltage disturbance at the connection points. In order to maximize the penetration of DG Power, the actual topology of distribution grids should change introducing active devices to control the voltage, especially in weak networks.
In this paper the integration of DG in a weak network is analyzed, that there the DG is connected to a MV/LV substation, using active devices. The studied active devices are: OLTC-PST and STATCOM. The contribution of these active devices to increase the installed DG power in weak networks is analyzed. An operation and control strategy for the Active Substation is verified by temporal power flow simulations.

Index Terms— Active Substation, Distributed Generation, Phase Shifting Transformer, STATCOM.

I. INTRODUCTION

Due to environmental concerns and the variable price of fossil fuels, renewable energy sources are getting more importance for power generation. Even if a Wind Farm, Solar Power Plant or Hydro Power Plant is connected to the transmission grid, these generation units can be defined as Distributed Generation (DG). The increasing of DG Penetration is already changing the network topology. This change of the network topology is due to the policies that aim the increase of renewable energies, subsidizing the electricity produced by renewable sources and the liberalization of electricity markets.

Increasing the Active Power penetration of DG is very important that there should be extracted the maximum Power that can be generated by DG. In this article a new concept of Active Network Management with different control devices are coordinated. This management strategy provides the possibility to increase the penetration of DG in the distribution network, ensuring the power quality and the voltage levels.

II. ANALYZED SCENARIO

The scenario proposed for this study is composed by a DG source connected to a MV/LV transformer substation through low voltage 380 V three-phase grid.

The equivalent grid of the distribution network is modeled as an ideal voltage source with a short-circuit impedance, Zsc (fig.1). In order to simulate a weak network, this short circuit impedance for a short circuit power of 1 MW.

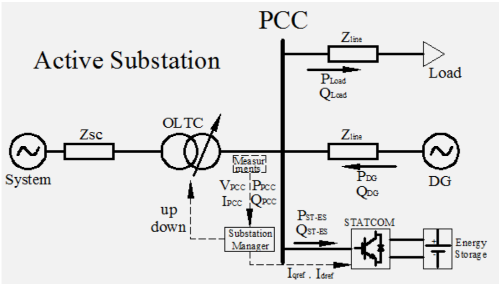


Fig.1. Active Substation

III. ANALYTICAL STUDY

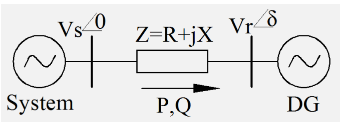


Fig.2. Analytical Model of the System

In the given system consider, $Vs = Vr = V$, in this case the Active Power (P) and Reactive Power (Q) can be found as:

$P + jQ = V \times I^{*}$

$I = Y \times V \times \left(1\angle\beta - 1\angle(\delta - \beta)\right)$

$I = V \times \{g \times (1 - \cos\delta) - b \times \sin\delta + j[b \times (\cos\delta - 1) - g \times \sin\delta]\}$

So,

$P = V^{2} \times [g \times (1 - \cos\delta) - b \times \sin\delta]$

$Q = V^{2} \times [b \times (1 - \cos\delta) + g \times \sin\delta]$

Where,

P =Active Power Flowed from Sending end to receiving end

Q = Reactive Power Flowed from Sending end to receiving end

Vs =Sending end Voltage

Vr = Receiving end Voltage

R = Equivalent Resistance

X = Equivalent Inductance

I =Current

$Y = \frac{1}{\sqrt{R^2+X^2}}$ = Admittance

$B = \tan^{-1}\frac{X}{R}$ = Admittance Angle

δ = Voltage Angle at receiving end

$g = \frac{1}{R}$ = Real part of Admittance

$b = \frac{1}{X}$ = Imaginary part of Admittance

Here $X = 0.03\ \Omega$, $R = 0.0075\ \Omega$, Is available, it has been calculated by using the typical 1MVA/20/0.38 kV Transformer catalog connected to a 20MVA, 20kV Distribution System,

Fig.3 shows that, by controlling the angle of Voltage at DG bus (δ) it is possible to increase or decrease the Power injection, there δ can be controlled by Phase Shifting Transformer (PST). The result shows that if δ be increased by 10^o there can be increase the Power injection by 0.8MW. The simulation is done for different consideration and the result is as following,

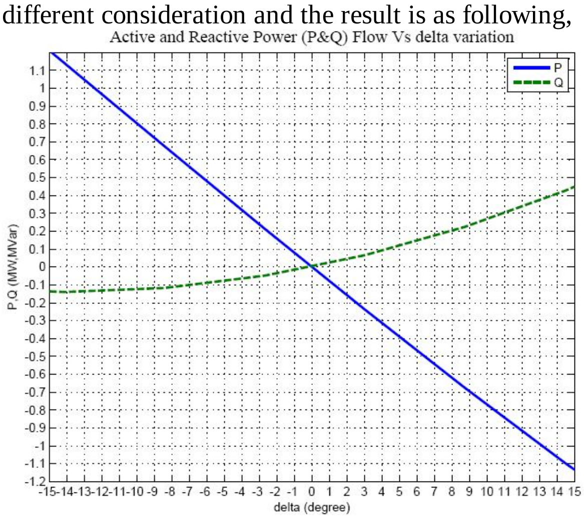


Fig.3. P&Q Flow Vs δ

IV. SIMULATION

In this system considered in a remote Area that 1MVA Load is needed to supply and a DG with capability of 1MW Power Generation is available. As the Load and Power Generation by DG is vary in nature (DG can be wind farm, MHP, or Solar farm), so there is needed to connect the Load and DG to the network that when the Load demand is low, DG should inject the Power to the network and in that case which DG don't generate enough Power or is turn-off, the Load should be supplied through the Network.

A. Programmable Voltage Source as DG (Ideal Case)

1) Simulation Result without any addition active device (simply DG is connected to the System).

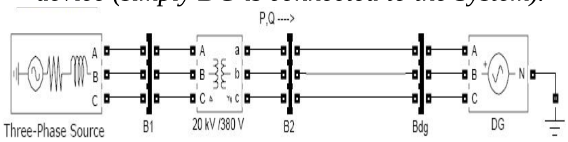


Fig.4. System without any active device

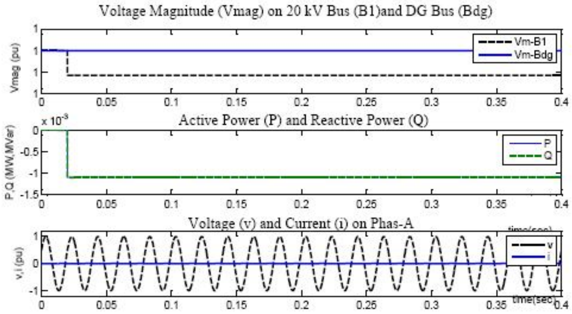


Fig.5. Voltage Magnitude at the Buses, P&Q Injection and v&i curves when No active Device

From Fig.5 it is observed that in case which there is not used Phase Shifting Transform (PST) or any other active device, the Power injection to the Network is zero (1kW and 1kVar only)

Now let's connect a Phase Shifting Transformer (PST) that this transformer shift the Voltage angle by 10 Degree in each step.

2) Simulation Result with Phase Shifting Transformer (PST) Connection (Here the PST is shifting the δ almost by 3.2 degree).

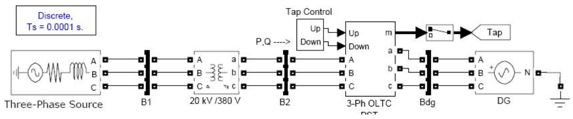


Fig.6. System with PST

Fig.7.

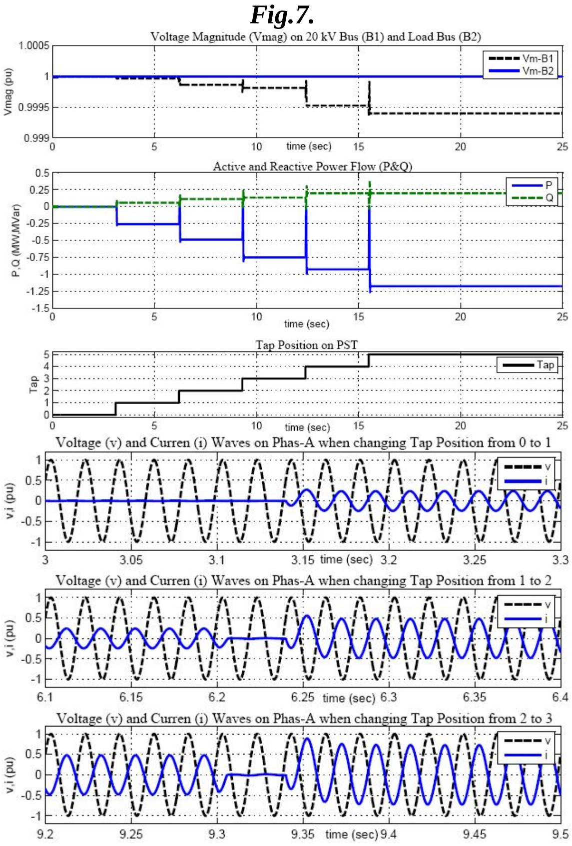


Fig.8. Voltage Magnitude, P&Q Injection and v&i curves when using PST

From Fig.7 it is observed that, PST changes the

Voltage angle and the System reaches to the Steady-State condition after 5 steps of the Tap Changing and the DG inject the active Power about 1.2MW and absorb Reactive Power about 0.2MVar. The Voltage Magnitude in 20kV Bus and DG Bus is same and 1pu. the Power injection is increased by Changing the Tap Position in fact regulating the δ Values (there positive sign show absorbing the Power and negative sign shows injecting the Power, so in fact the DG absorb a low value of Reactive Power (Q) but inject a high value of Active Power to the System.). Here the result is almost same to theoretical analyses that was increased the Power injection up to 0.8MW in which δ was increased by 10^{o}

There the PST angle is controlled by getting reference from amount of Power Generation by DG that there should be extracted the Power higher than 0.8MW and lower than 1.1 MW (Because DG have a capability of 1 MW Power Generation with a Reactive Power constraint of lower than ±0.5MVar).

3) Simulation Result with PST and 1MVA Load 1MVA (0.8MW, 0.6MVar)

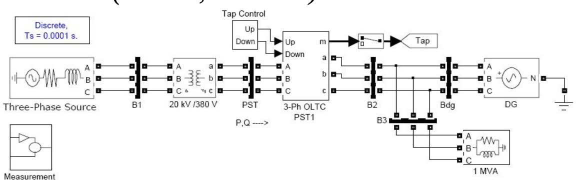
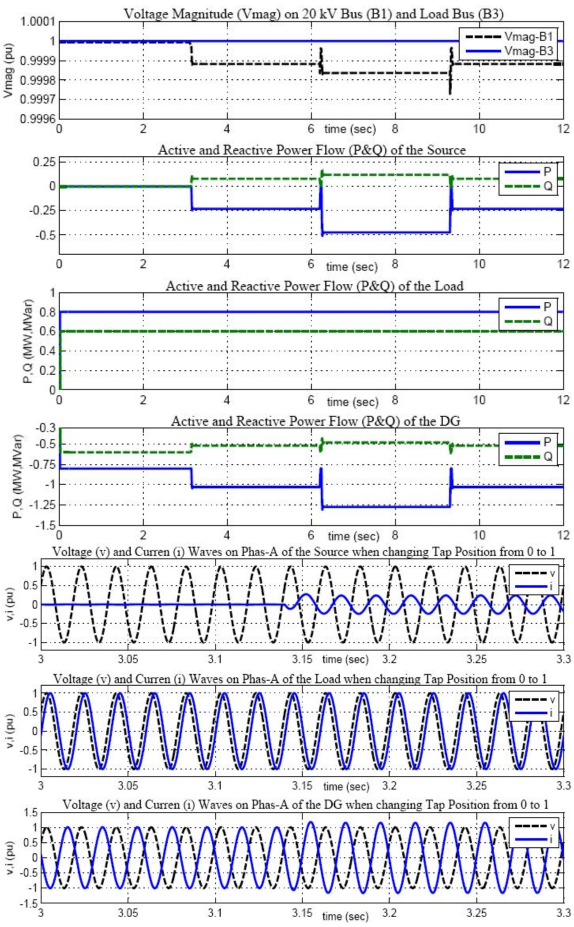


Fig.9. System with PST and Load



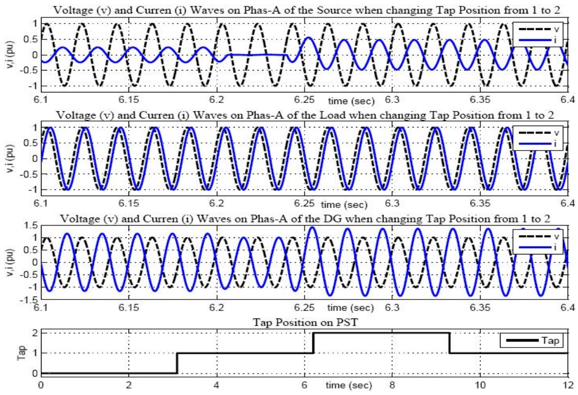


Fig.10. Voltage Magnitude, P&Q injection and v&i curve when using PST and also supplying the Load

As Fig.9 shows, in this case higher than 0.5 MVar of Reactive Load is supplied by DG and cannot be supplied from the System (when using the Phase Shifting Transformer it permit a constant value of the Active and Reactive Power Flow in each Tap or Phase Degree). The Reactive Power supplying by DG may be higher than Q_{lim} of the DG. Also the DG Power Generation is not continuously constant, because it can be a Wind Power Plant, Solar Power Plant or Micro Hydro Power Plant etc. There the Source of Energy (Wind Speed, Solar Radiation, Water Flow, etc.) is changing due to the season and for some duration of time DG may be off, so the Load should by supplied through the Network. Incase which the DG is off, the result is shown below,

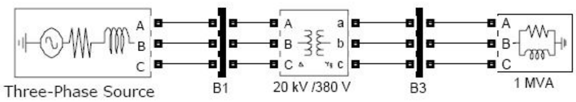


Fig.11. System when DG is Disconnected

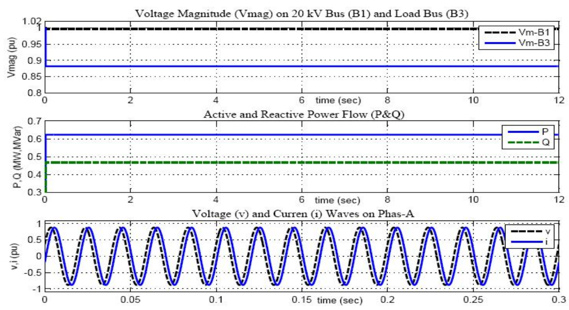


Fig.12. Voltage Magnitude, P&Q and v&i curves

Fig.11 shows, that the V_{mag} is come down (almost to 0.92pu) and it have negative impact on the Load, as the Active Load supply is Almost 0.6 MW and Reactive Load supply is Lower than 0.5 MVar, whereas the Active Load is 0.8 MW and Reactive Load is 0.6 MVar. The reason of this negative impact is that which the Voltage is com down. As standards do not permit the Voltage variation higher than ±5%, so there in both reason, Voltage Control and Reactive Power Compensation that was supplied by DG, the Reactive Load should be compensated. Here the

Reactive Load is compensated by STATCOM.

B. Reactive Power Compensation

1) STATCOM

The Static Synchronous Compensator (STATCOM) is a shunt connected Flexible AC Transmission System (FACTS) device used as a device to control the reactive power exchange at the PCC. This gives different choices:

- Reactive power control the complete system is required to produce or absorb a constant specific amount of reactive power.
- Automatic voltage control—the voltage in the PCC is controlled. This implies that the complete system can be ordered to produce or absorb an amount of reactive power to the grid in order to compensate deviations on the grid voltage.

The STATCOM is modeled as a three phase voltage source inverter connected to the grid by means of an inductive filter.

2) STATCOM Controller

The STATCOM is consisting of a high value Capacitor that is connected through an inverter to the Grid Bus. For Reactive Power compensation, it inject appropriate value of current to the system with rapidly control of firing angle.

Here for controlling the firing angle of converter, directly the Load Current (Iabc) is given as reference current and it is changed to Idq as:

$$i_d = \frac{2}{3}\left[i_a\cos\theta + i_b\cos\left(\theta - \frac{2\pi}{3}\right) + i_b\cos\left(\theta + \frac{2\pi}{3}\right)\right]$$

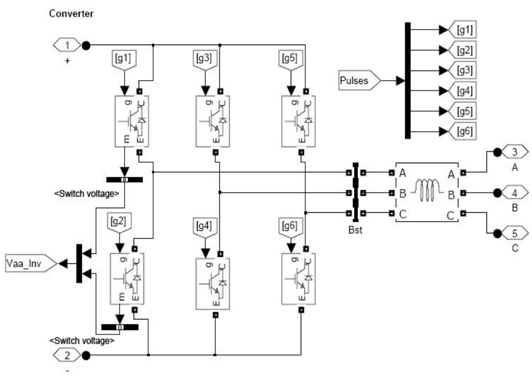
$$i_q = \frac{2}{3}\left[i_a\sin\theta + i_b\sin\left(\theta - \frac{2\pi}{3}\right) + i_b\sin\left(\theta + \frac{2\pi}{3}\right)\right]$$

There, i_d, i_q is current along the d and q axes respectively, i_a, i_b, i_c is current of phases a,b,c respectively, $\theta = \omega t$

Here i_{abc} of the load, i_{abc} of the STATCOM and i_{abc} of the source is changed to i_{dq} and i_q of Load is compared with i_q of STATCOM but i_d of Load is compared with i_d of the Source. The error is controlled by PI and PID Controller and the firing angle is found as:

$$\alpha = \tan^{-1}\left(\frac{i_{q\,err}}{i_{d\,err}}\right)$$

Finally the θ_1 is found as: $\theta_1 = \theta + \alpha$ and it is given to gate control logic. The block diagram is shown below,



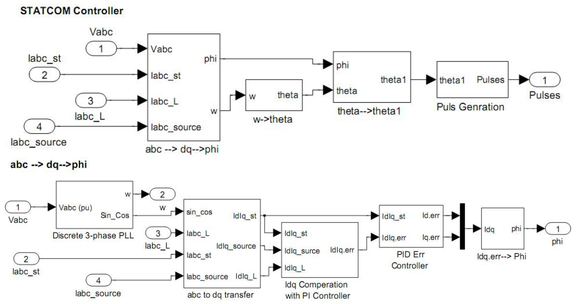


Fig.13. STATCOM and STATCOM Controller

3) Simulation Results

a) STATCOM without DG (to improve Voltage at Load Bus)

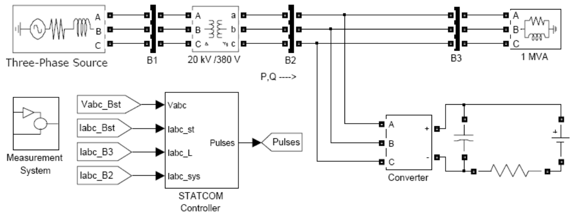


Fig.14.System when supplying the Load through Network and STATCOM

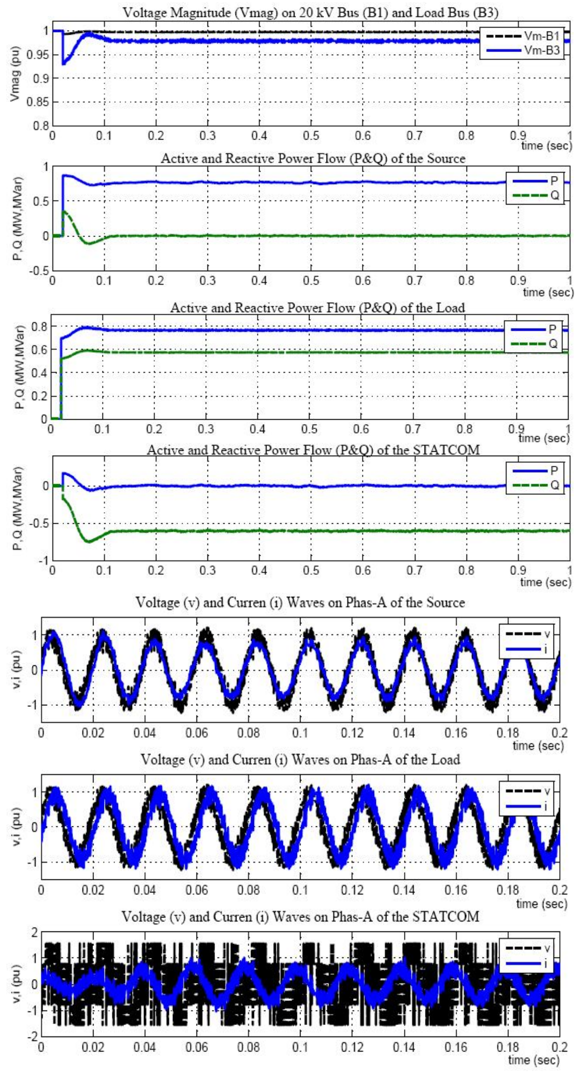


Fig.15. Voltage Magnitude, P&Q and v&i curve when supplying the Load through the Network and STATCOM

Fig.14 shows that by compensating the reactive Power through STATCOM, the Voltage improve near to 1 pu and the Load P&Q is almost 0.8MW and 0.6 MVar Respectively.

The Voltage and Current in Phase-A of Source and Load is sinusoidal and it shows that in the source there is not any phase different between Voltage and Current waves.

b) DG integration, with STATCOM but without PST

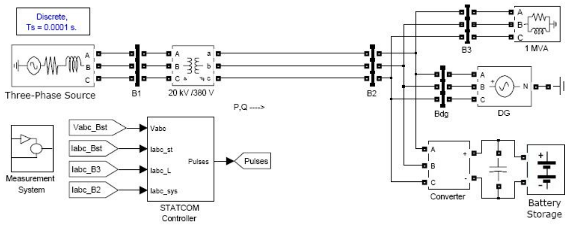


Fig.16. ***System when using STATCOM and supplying the Load whithout PST***

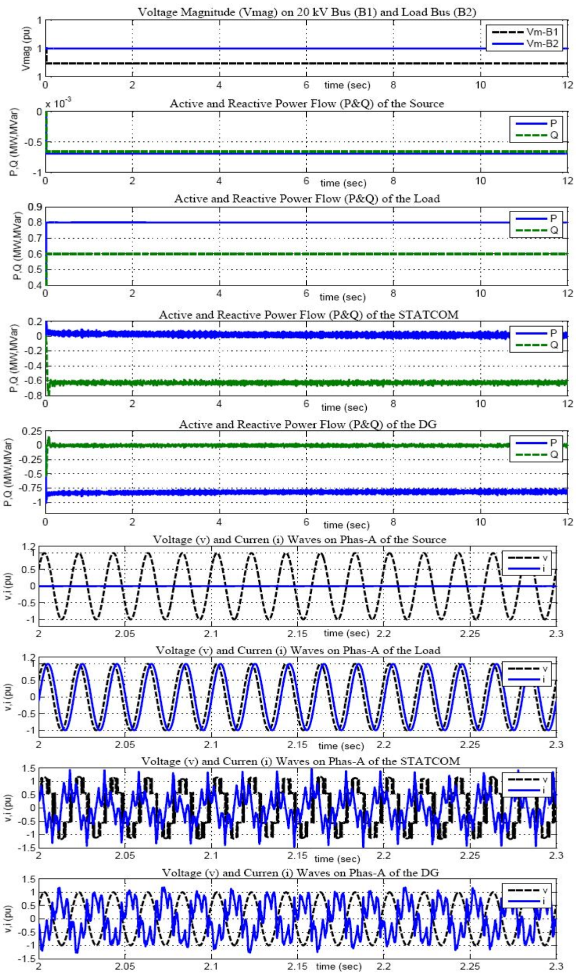


Fig.17. ***V_{mag}, P&Q and v&i curves when using STATCOM and supplying the Load without PST***

Fig.16 shows that the DG only supply the Load but there is no any injection Power to the Network, and also it shows that the Reactive Power is compensated by STATCOM but STATCOM does not help to inject the Power to the system.

c) DG Integration to the System, with STATCOM and PST

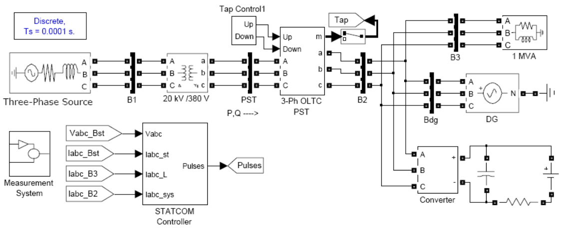


Fig.18. ***System when using STATCOM and PST and supplying the Load***

Fig.18 shows that, more than 250KW Active Power is injected to the System, it is due to capability of the DG, if the capability of DG was high, we could inject more Active Power but there the capability of DG is 1MW, it supply 0.8MW Load and inject about 250KW to the System. The Reactive Power is compensated by STATCOM and DG supply only Active Power, in this case we can extract more Active Power from DG.

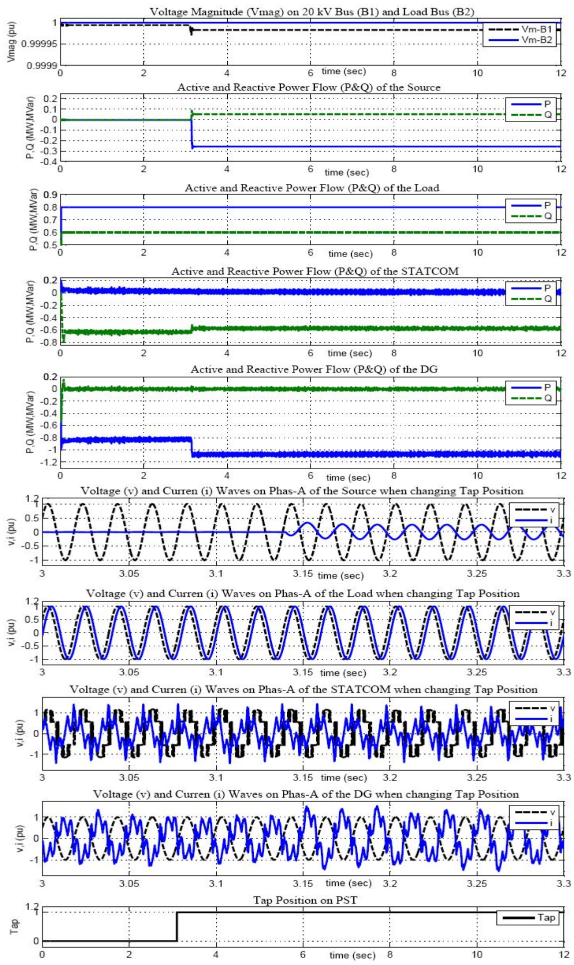


Fig.19. ***V_{mag}, P&Q and v&i curves when using STATCOM and PST and supplying the Load***

C. Wind Turbine Integration

In the case when the wind turbine is used as Distributed Generator (DG), the Generation is Constant in the canstant wind speed, so if the Power Consumption (the power which is extracted from DG) is lower than DG Power Generation, the voltage is increased and viceversa. So there the Power Injection can be controlled by controlling the Voltage at the PCC. There the wind geration is converted in DC and again it is converted to AC with 50 Hz frequency. The result of a 1.5 MW Wind Turbine is shown below.

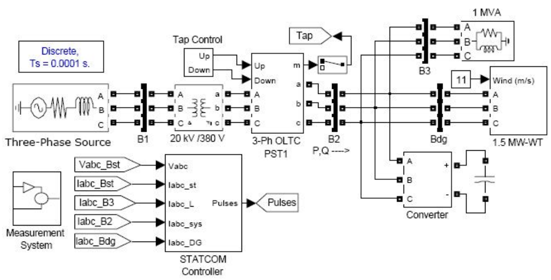


Fig.20. Wind Turbine Integration System

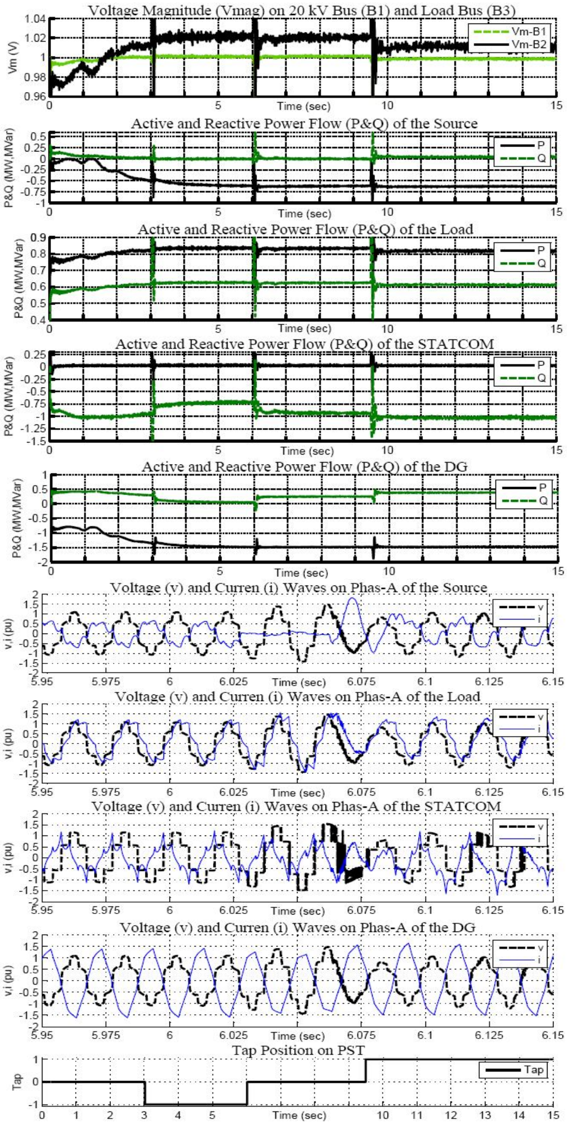


Fig.21. V_{mag}, P&Q and v&i curves in Wind Turbine Integration

Fig.20 shows that when the Power Injection is low, Voltage at PCC is higher than 1pu that it causes the Load be exited from its nominal value 1MVA (Active Power is exited from 0.8MW and Reactive Power is exited from 0.6 MVar) but by changing the Phase Degree the Power Injection is increased and the Voltage comes down almost in 1pu.

D. Tables

Table1. Wind Generator integration

Time Period Sec	Source		DG		V_m pu	
	P_S MW	Q_S MVar	P_{DG} MW	Q_{DG} MVar	B_1	B_2
3-6	-0.61	0.001	1.48	-0.052	1	1.025
6-9	-0.62	0.002	1.48	-0.38	1	1.02
9-up	-0.63	0.035	1.48	-0.37	1	1.015

Table2. Load and STATCOM Response

Time Period Sec	Load		STATCOM	
	P_L MW	Q_L MVar	P_{ST} MW	Q_{ST} MVar
3-6	0.83	0.63	0.04	-0.72
6-9	0.82	0.62	0.04	-0.94
9-up	0.81	0.61	0.04	-1.02

CONCLUSION

In this article it has been demonstrated how the integration of DG in weak electrical networks can be maximized introducing active devices in the MV/LV substation. It has been presented the concept of an Active MV/LV Substation, integrating active devices as: OLTC, STATCOM. It has been demonstrated that the control of the voltage level at the PCC is possible monitoring only the local signals at the substation, and with an adequate control/operation strategy of these active devices. An operation and control strategy for the Active Substation has been presented and the performance in a weak grid has been verified by temporal power flow simulations.

For a future electrical network where a high amount of electricity will be produced by DG, the use of active devices seems to be necessary in order to increase the active power injection capability in weak networks. In this context the Active Substations are a suitable solution to increase the DG penetration.

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