Active system for voltage control in wind generation units

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Abstract

A combined system that permits a wise control of reactive power in WECS (Wind Energy Conversion Systems) without harmonic generation is presented. In the case of asynchronous generator, it uses the thyristors of the usual soft-starting system to connect a TCR (thyristor controlled reactor) and a small-rated active filter (PWM-VSI) so its implementation is very economical.

1. Introduction

Wind power is going to play an important role in the electric generation in several countries. In EU the wind generation capacity exceeded 23 000 MW by the end of 2002 (with an annual growing in the year 2002 over 30%). Operation of wind turbine installations may affect the steady-state voltage in the connected network.
Voltage regulation problems arise in the power system as a consequence of grids being made dependent on wind power, a matter of growing concern as wind power gets more important in the power balance. The voltage fluctuations imposed by the wind farm will depend on the characteristics of the grid and the type of generator used. There is a risk for flicker if large periodic power fluctuations are produced by the WECS (wind energy conversion system).

The voltage level at the consumers is regulated by internation standards, e.g. EN50160. Due to the impedance of the conductors the voltage level will change along the feeder depending on the wind power production and the consumer load. Load-flow analyses must be done to assess this effect and to ensure that the wind turbine operation does not bring the magnitude of the voltage outside the required limits.

Voltage control problems caused by deficit of reactive power in the grid can be reduced by installation of fixed or mechanically switched shunt capacitors, but this do not help on voltage fluctuations caused by varying output of wind generators. Static Var Compensation have been recognized to reduce the flicker effect. They can be used to dynamically control the network voltage and thus increase the size of wind farms that may be connected to the existing weak electrical distribution networks without any need for network upgrading. Network upgrading and the construction of additional circuits is very expensive and it has significant environmental impacts.

If embedded wind generation is not only capable of supplying active power but also provide reactive power properly controlled, it can be used for voltage regulation, reduction of losses, increase of the steady-state transmittable power, and transient and dynamic-stability improvements (to increase the first swing stability margin and provide power oscillation damping) [1], which adds an important economic and technical value to this type of generation. In this paper, a combined system is proposed, in order to control the voltage in the terminals of the WECS.

2. Voltage control

In figure 1 the connection of a wind farm to the power system is shown, where R and X are, respectively, the resistance and reactance of shortcircuit, and Pg and Qg are the active and reactive power generated in the wind farm. E is the voltage of the ideal source in the Thevenin equivalent of the power system. At the same pcc there is a load characterized by its demand curve (Pload + j Qload).

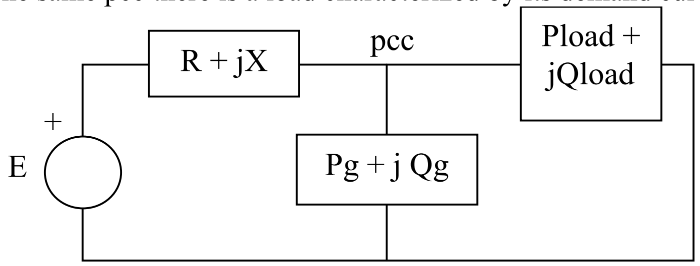

Fig.1: Connection of wind farm and load at the point of common coupling.

The variation of the voltage can be expressed as

$$\underline{\Delta U} = \underline{E} - \underline{U} = (R + jX)\underline{I} = (R + jX)\frac{P - jQ}{U} = \frac{RP + XQ}{U} + j\frac{XP - RQ}{U}$$

where P and Q are the total active and reactive power absorbed from the power system (load + wind generation).
The variation of the voltage in the point of common coupling of the wind farm to the grid can be calculated by solving the following equation:

$$U^4 + \left[(XQ + PR) - E^2\right] \cdot U^2 + \left[(XP - QR)^2 + (XQ + PR)^2\right] = 0$$

In the following figures it is shown that the voltage at the pcc varies with the total (net) active and reactive powers (The values are in per unit. Positive values of P and Q mean injected powers). The network impedance is 0.5 p.u., with an argument of 60 degrees. The voltage of the ideal source, E, is considered to be 1 p.u. in figure number 2, and 0.9 p.u. in figure number 3.

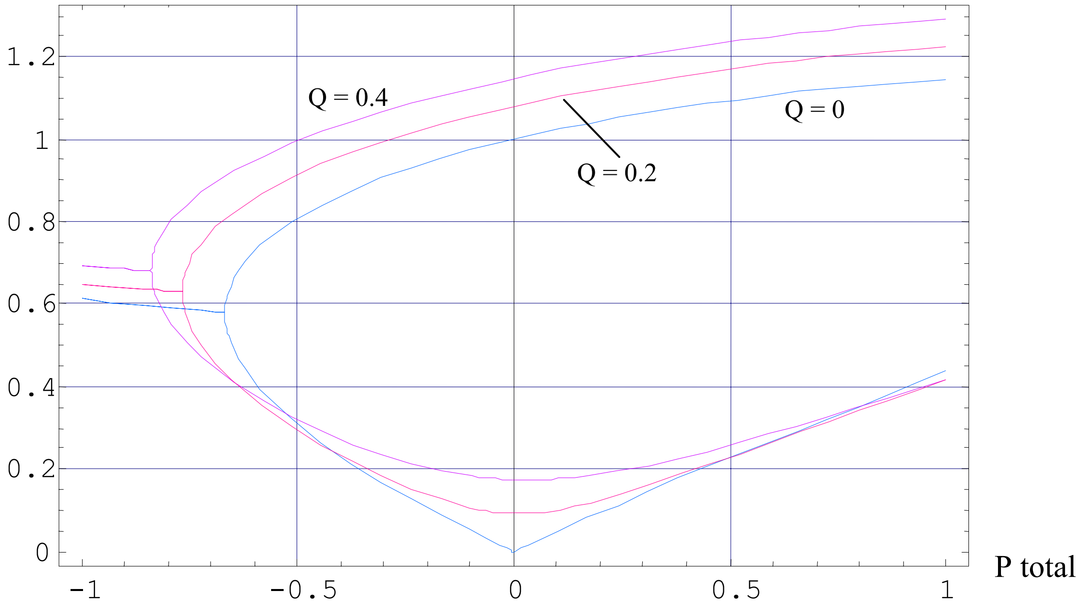

Fig. 2: Voltage (in p.u.) at the pcc when E = 1 p.u.

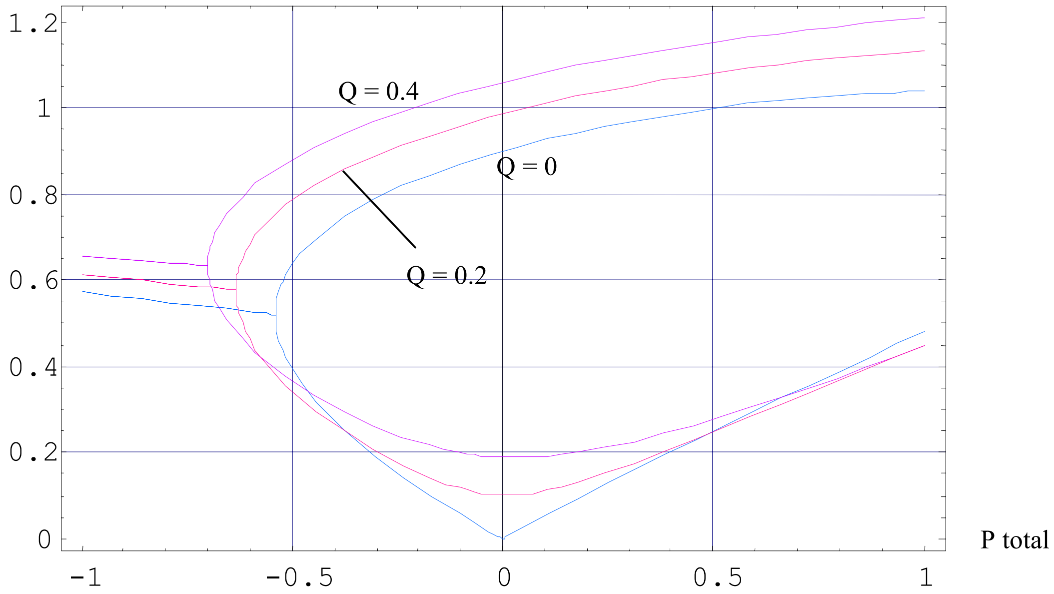

Fig. 3: Voltage (in p.u.) at the pcc when E = 0.9 p.u.

The voltage falls as the power import is increased, and the rate of decrease of voltage accelerates at high loads. Injecting reactive power it is possible to bring the voltages at values near 1 per unit. With generation of active power (for instance, if the wind farm is alone), the voltage rise, but the increase can be reduced with importation of reactive power. In resume, the management of Q permits adjust the voltage at the pcc at the required level.

The reactive power output can be automatically controlled in response to voltage measured at the wind farm terminals (available now from some wind turbine suppliers) or with a function equivalent to 'line drop compensation' for transformer tap changers, in order to control the voltage at some point on the network without having to measure voltage at that point (also available now from some wind turbine suppliers). It can also be controlled as a function of output power or changed for different seasons or different times of day, either automatically or remotely by the operator of the system. The most flexible solution for the power system operator is to have remote control of the wind farm reactive power output.

Nowadays, most of the WECS use capacitors to obtain a power factor near the unity. Capacitors are usually connected in stages, but the voltage is not regulated. With this strategy (obtain PF=1), a disconnection of the wind generator can occur. In some countries, it is mandatory that if the voltage is below 0.85 per unit, acts the protection of undervoltage (without any delay, instantaneously). The same occurs if voltage overpass 1.1 p.u. This can lead to instability.

The risk of voltage collapse in the steady state is an issue only for sections of network which are weakly connected to the rest of the system, and which have insufficient local generation feeding them. Additions of local generation (whether powered by wind turbines or by any other type of prime mover) should reduce power flows and mitigate the risk of voltage collapse. Voltage collapse is the catastrophic result of a sequence of events leading to a low-voltage profile suddenly in a major part of the Power System.

Voltage control and voltage instability are local problems. However, the consequences of voltage instability may have a widespread impact. The main factor causing voltage instability is the inability of the Power System to meet the demands for reactive power in the heavily stressed system in order to keep desired voltages.

Voltage stability is not expected to be an issue when connecting wind power generation to a healthy Transmission System or even to a weak sub-network provided that the reactive power capabilities of new wind generators can be comparable to that of existing conventional generators.

Besides, the variable nature of the wind, together with the inherent characteristics of the wind turbine leads to variations in the shaft torque applied to the wind generator. The generated power is dependent on the wind speed and wind speed fluctuations are reflected in uncontrollable output power variations. Traditionally, fixed speed technology (induction generator) has been utilized for electricity generation with wind turbines. This technology will however transfer torque variations from the shaft to variations in active and reactive power, which can lead to flicker problems. (The phenomenon of flicker is the result of rapid fluctuations in power or reactive power, causing rapid fluctuations in voltage, sufficient to cause perceptible ‘flicker’ of lighting.). Periodic power pulsations may also be caused by aerodynamic effects when each blade pass in front of the tower (shadow effect or 3p effect), wind shear effect (different wind speeds at different heights), yaw errors, misalignment of rotor blade angles, wind speed turbulence intensity, the control system of the wind turbine or mechanical resonances (blade and tower resonances) as can be seen in a frequency spectrum of the active generated power.

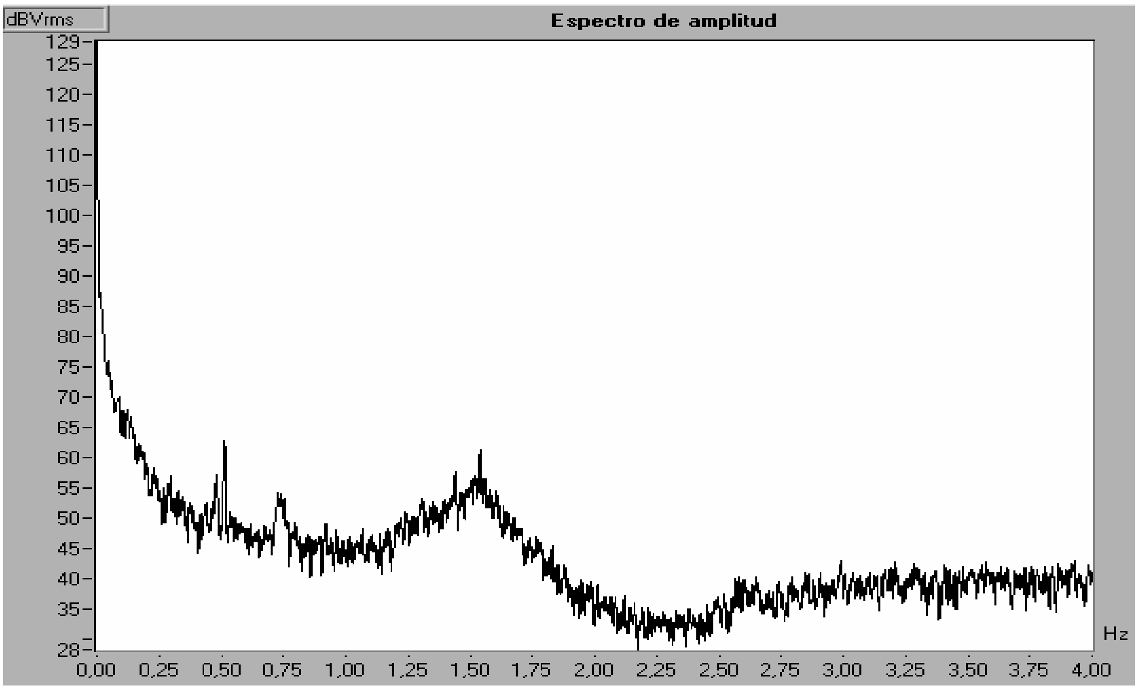

Fig. 4: Example of power spectrum in a wind generation unit.

The simplest possibility to inject reactive power is to use fixed shunt capacitors, but obviously it is not convinient if the reactive power has to be changed. Another possibility is to control the number of capacitors connected. It is the case of the thyristor-switched capacitor system (TSC) in which several capacitors in parallel are connected or disconnected with a switch or with bi-directional thyristors valve. (A damping reactor serves to de-tune the circuit to avoid parallel resonance with the network). Each capacitor conducts for an integral number of half-cycles. The reactive power is therefore not continuously adjusted, but in steps. Besides, a resonant condition between the capacitor and the power system can be created at several capacitance values. The magnitude of the amplification will be given by the quality factor of the resonance circuit, i.e. by the resistance connected to the circuit. A much more fine regulation can be obtained with a Thyristor Controlled Reactor. But this system absorbs a current with waveforms different from the pure sinusoidal, i.e., it generates harmonic currents. These currents lead to voltage distortion, and there is the possibility to excite a harmfull resonance, amplifiying the levels of harmonics and their effects. It is important to cancel the harmonics and isolate the system from the grid. This can be achieve in a cost – effective way by the use of a hybrid filter, that consists in the combination of a small rated active filter and a passive branch (the most simple option is to use the capacitors for fundamental power reactive compensation).

3. Configuration proposed.

Until now, wind generation has not been considered for providing voltage support. As has been said, voltage support mantains grid voltage close to a nominal value by injecting or absorbing VARs in the system. Dynamic compensation can mitigate voltage fluctuations and flicker caused by wind farms and management of reactive power helps to preserve or restore dynamic voltage stability of the system with fault situation in the grid, fast aristing overvoltages caused by sudden islanding, and potential voltage collapses due to cumulating deficit of reactive power.

Variable speed wind turbines are capable of varying the reactive power at a given active power and terminal voltage in some extent. In a variable speed wind turbine with doubly fed induction generator, this is done by changing the direct component of the rotor current. In a variable speed wind turbine with direct drive synchronous generator, this is done by changing the current at the grid side of the power electronics converter that couples the generator to the grid. If power electronics are applied in the wind turbines the resulting level of harmonics have to be below the limits set in the standards. The power quality from wind turbines and wind farms ared calculated on the basis of IEC 61400-21. [8]. To manage a big quantity of reactive power, the size (and cost) of the converter is also high. It can be more efficient to install a SVC [9] and an hybrid filter to enlarge the possibilities of control of reactive power and to reduce the injection of harmonics into the grid, avoiding also the possibilities of resonances. [2-7].

The combined system would be the shown in the figure number 5

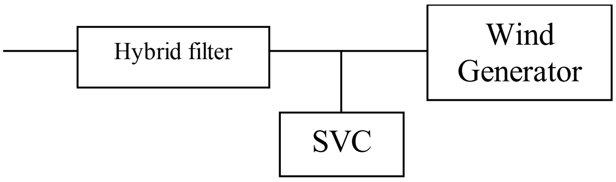

Fig.5: Combined system for control of reactive power in wind generators.

A great part of the wind power generators are asynchronous, because of its robustness and cost effectiveness. Induction generators, however, do not contribute to regulation of grid voltage nor frequency, and they are substantial absorbers of reactive power. Induction generators are known to have large starting currents at the time of connection to the grid. Soft starter systems (two thyristor valves in anti-parallel in the terminals of the wind generator) are used in order to reduce the high currents injected in the initial period, and one o several banks of capacitors to compensate the reactive power absorbed by the machine. The thyristors of these soft starters are used only during short periods of time, and they could be used to control three reactors as a TCR.

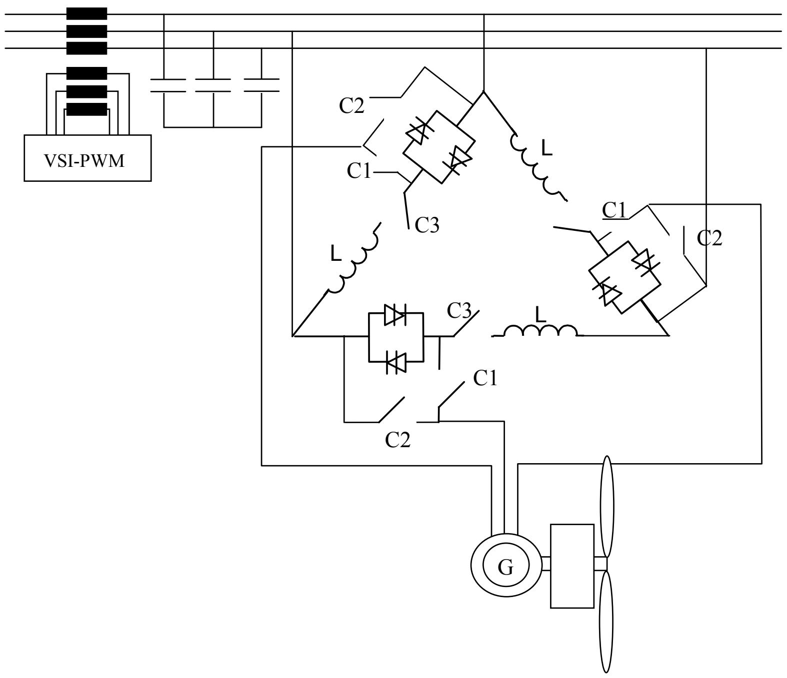

Fig. 6: Active system proposed for induction wind generators

In the connection of the system proposed, contactors C1 are closed and C2 and C3 are opened. The conduction angle of the thyristors in anti-parallel increase from cero to total conduction, so the initial current is limited so preventing the high inrush current that would have in a direct connection of the electrical machine to the grid. Then, contactor C2 are closed. Now, it is possible to reopen C1. Then C3 are closed and the thyristors are connected in series with the reactor in a classic TCR configuration, delta connection. In a Thyristor Controlled Reactor (TCR), the current can be controlled from maximum (total conduction of the thyristor valve) to zero (open circuit) by the method of firing delay angle control (the closure of the thyristor is delayed with respect to the peak of the applied voltage in each half-cycle, and thus the duration of the current conduction intervals is controlled. Usually TCR reactors are of air core type, glass fibre insulated, epoxy resin impregnated. There are fixed or switched capacitors connected in parallel to provide with the required reactive power.

The reactive output power (capacitive or inductive) of the compensator can be varied to control the voltage at given terminals of the transmission network so as to maintain the desired power flow under possible system disturbances and contingences. The susceptance presented by each branch of the TCR is a function of the conduction angle σ,

$$B_L(\sigma) = \frac{\sigma - \operatorname{sen}\sigma}{\pi w L}$$

For identical operation in positive and negative half cycles of the voltage, only odd harmonics are generated, and under balanced conditions, the triple- n harmonic currents (3rd, 9th, 15th, etc.) circulate in the delta and do not enter the power system. The amplitudes of the different harmonics n are also a function of alpha, and can be expressed

$$I_n = \frac{4}{\pi}\frac{U}{X_L}\left(\frac{\operatorname{sen}(n+1)\alpha}{2(n+1)} + \frac{\operatorname{sen}(n-1)\alpha}{2(n-1)} - \cos\alpha\frac{\operatorname{sen} n\alpha}{n}\right)$$

The active filter consists in a dc/ac converter, with a capacitor in the dc bus, whose output voltage is totally controlled by a PWM control (Pulse Width Modulated voltage-source inverter PWM-VSI)

The active unit is controlled in such a way as to present an output voltage vc = K ish, where ish is the harmonic content of the current that enters the local grid of the wind farm.

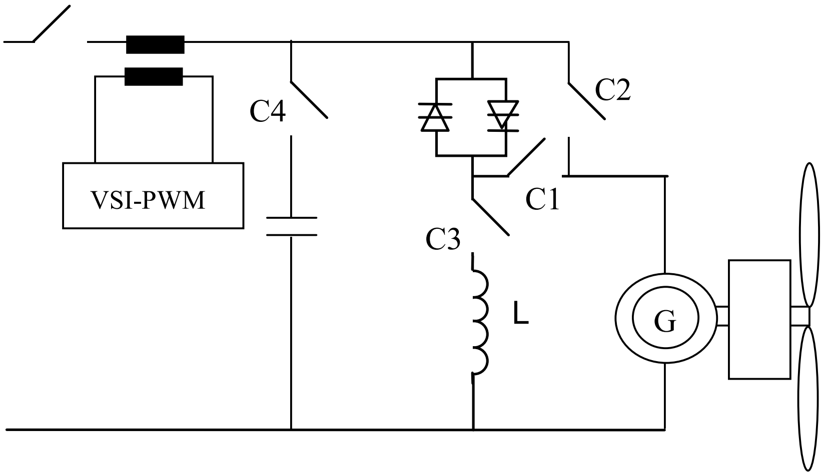

Fig. 7: Single phase configuration.

No fundamental voltage is applied to the active filter; this results in a great reduction of the voltage rating of the active filter. The function of the active filters in this topology is not to cancel directly the harmonics of the load, but to improve the filtering characteristics of the shunt passive branch (capacitor) and to solve the problems of the shunt passive branch used alone. The voltage-source PWM inverters are inserted in the system through current transformers. The purpose of the CT's in not only to isolate the PWM inverters from the power system, but also to match the voltage and current rating of the PWM inverters with that of the power system.

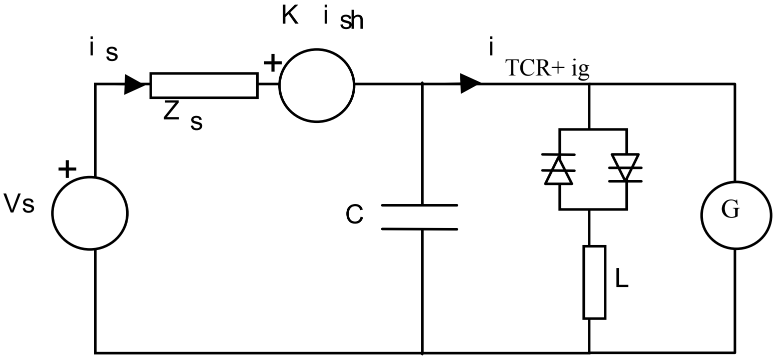

Fig. 8: Single-phase equivalent circuit of the system proposed.

From an easy analysis of the circuit, the expressions for the filtering characteristics are

$$Is_h = \frac{1}{Zs_h + K + Z_{ch}} Vs_h + \frac{Z_{ch}}{Zs_h + K + Z_{ch}} I_{TCRh}$$

where I_{sh} is the harmonic component of order h of the current in the line; I_{TCRh} is the harmonic component of order h of the TCR current (assuming that the harmonic content of the electrical machine is negligible; V_{sh} is the harmonic component of order h of the distortion in the voltage present in the power system; Zs is the impedance of the power system; K is the gain of the active filter, and Zch is the harmonic impedance of the capacitor, 1/hwC.

In the following figure a simulation of the sistem proposed is shown. The TCR is fired at an angle convient for compensation of the voltage (50 degrees in the figure). It can be seen than, before the connection of the active part, a harmfull resonance was excited. A disfavourable case has been chose to see the operation of the system.

The parameters used are: $R_{line} = 0.01\Omega$; $L_{line} = 0.3564$ mH; $C = 250$ μF; $L_{reactor} = 32$ mH; $K = 20$

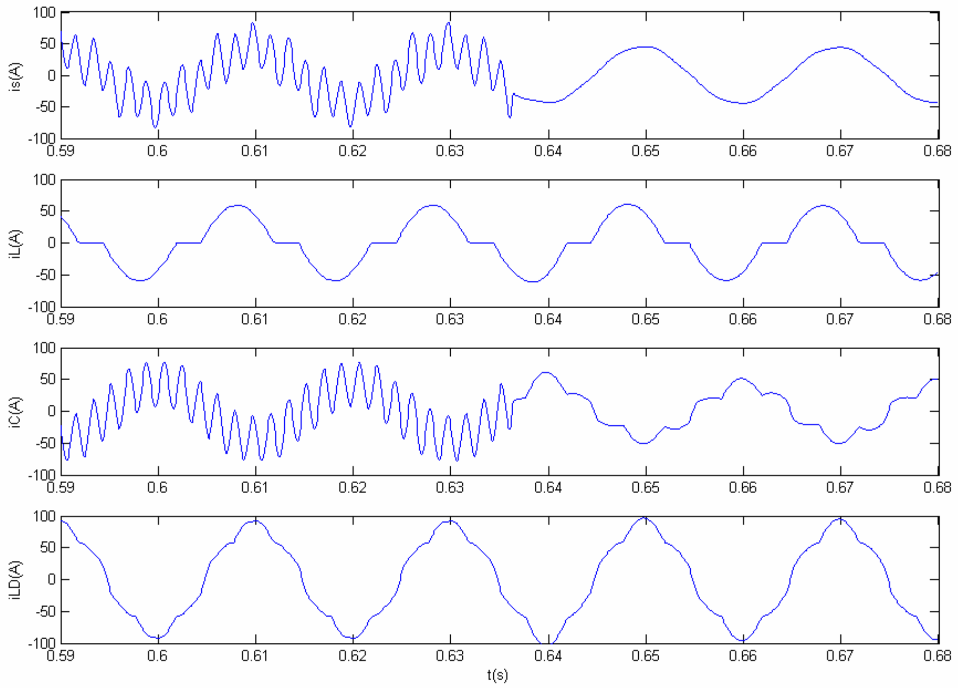

Fig. 9: Waveforms of the actuation of the system proposed.

The active filter manages to regulate the amount of harmonics flowing in the capacitor. The performance is very good in eliminate the resonances and the harmonic components in the current in the source. It also acts as a harmonic isolator between the source and the compensation system, eliminating the parallel resonance between the capacitor or shunt passive filter and the source impedance, and preventing the harmonic current produced by the source harmonic voltage from flowing into the shunt capacitor.

The upper graphic of the figure corresponds to the line current. In this example, before the operation of the series active filter, a resonance was excited, but it is strongly attenuated with the operation of the filter, resulting in a nearly sinusoidal current.

The second one is the current in each reactor. As they are connected in delta, the current in the line has much lower harmonic content, as can be seen in the bottom graphic. The other graphic shows the current in the capacitor. Before the actuation of the active filter it forms part of the resonant circuit. After the operation of the filter, nearly all the harmonic current enters in the capacitor.

If the resistance K is much larger than the source impedance, variations in the source impedance have no effect on the filtering characteristics of the shunt passive filter, thus reducing the source harmonic current to zero.

The terminal harmonic voltage corresponds to a voltage drop across the passive filter. The source harmonic voltage does not appear on the load side because it applies across the series active filter.

The harmonic component of order h of the voltage at the point of common coupling (pcc), V_{pcch}, is

$v_{pcch} = -\underline{Z}_{ch}\,\underline{I}_{TCRh}$

The output voltage of the series active filter, is given by

$$v_{fh} = \underline{Z}_{f}\,\underline{I}_{TCRh} + \underline{V}_{sh}$$

In the following figure the instantaneous power in the series active filter (K = 20) is shown.

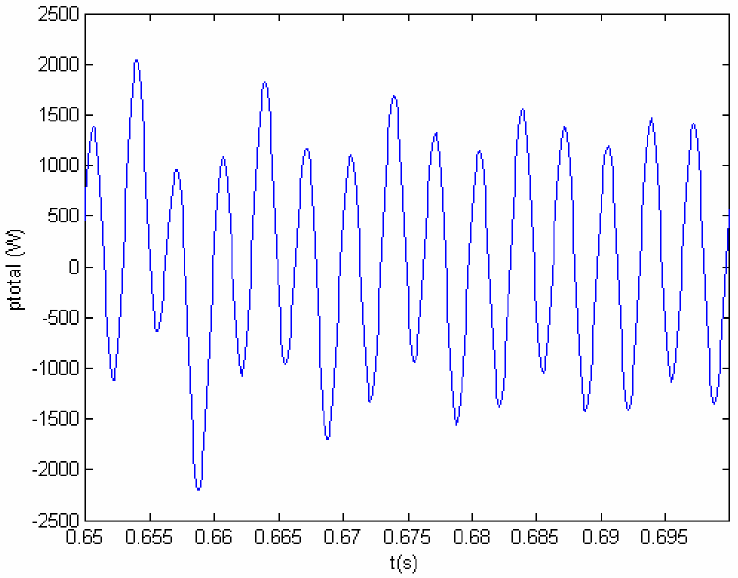

Fig.10: Instantaneous power in the series active filter.

Only about 2 kW are required in this example in the active part. Nevertheless it is necessary a bigger size to cope the initial transients.

4. Conclusions

In this paper a new combined system for the management of reactive power and control of voltage in wind generators without generation of harmonics is shown. The system is specially suitable with induction wind generator. In these systems, the thyristors of the soft starter are used to control the firing of a TCR, delta connection.

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