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Improved Vector Control Strategy for Current-Source Converters Connected to Very Weak Grids

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Introduction

A power grid is weak when SCR and very weak when SCR. The worst case scenario occurs when SCR. In the literature, extensive research work has been conducted to address the connection of voltage-source converters (VSCs) to weak grids. However, no effective method is reported to facilitate the integration of VSCs to a very weak grid, i.e., at SCR, using the conventional phase-locked loop (PLL)-based vector control strategy. Moreover, and up to the best of the authors' knowledge, the interconnection of \ current source converters (CSCs) to weak and very weak grids has not been reported. In spite of the utilization of VSCs in different applications, the recent advances in semiconductors and magnetic components help CSCs to gain a widespread acceptance in wind generators, PV systems, static synchronous compensators, and motor drives.

As a brief comparison, the key characteristics of VSCs and CSCs are summarized as follows.1) The dc side element in the VSC is a capacitor whereas it is a choke in the CSC. The power losses in the dc choke is usually 2%–4% whereas it is around 0.5% in the dc-linkcapacitor.2) The reliability of the dc choke is much higher than the electrolytic dc-link capacitor. The reliability of the dc-link capacitors significantly increases if the newly improved film capacitors are used. However, film capacitors are still challenged by a relatively high price and less capacitance per unit volume as compared with the electrolytic type.3) The semiconductor switch in the VSC is usually the insulated-gate-bipolar-transistor (IGBT). An additional diode has to be added in series with each IGBT if it is used in CSCs to increase the reverse voltage withstanding capability, but this almost doubles the switching losses. However, the recently developed reverse-blocking IGBT and the integrated-gate commutated-thyristor (IGCT) switches that withstand high reverse voltages are emerging; therefore there will be no need for the added series diode.4) CSC offers additional short-circuit protection as compared to the VSC due to the directly controlled dc current.5) VSC is a buck inverter as the dc-link voltage should be at least twice the maximum of the ac phase voltage to avoid over-modulation. On the contrary, the CSC is a boost inverter and, therefore, is more flexible in grid integration applications.

In this project, the integration of the PLL-based vector-controlled CSC to a very weak grid, i.e., at SCR , is successfully achieved. Under weak grid conditions, vector-controlled converters suffer from instability and degraded performance due to the implementation of the synchronous reference frame (SRF) PLL. To preserve the system stability, major limitations on the amount of injected active power to the weak grid should be considered. In it was reported that, at SCR , no more than 0.4 per-unit (p.u.) of active power could be injected from the conventional vector-controlled VSC. In it was reported that a 0.6–0.7 p.u. of active power could be injected. It was shown that a high bandwidth PLL contributes to the increase of the negative real part of the converter output impedance, and hence the converter does not act as a passive system, which in turn challenges the system damping.

ELECTRICAL GRID

An "'electrical grid'" is an interconnected network for delivering electricity from suppliers to consumers. It consists of generating stations that produce electrical power, high voltage transmission lines that carry power from distant sources to demand centers, and distribution lines that connect individual customers

Power stations may be located near a fuel source, at a hydroelectric dam site, or to take advantage of renewable energy sources, and are often located away from heavily populated areas. They are usually quite large to take advantage of the economies of scale. The electric power which is generated is stepped up to a higher voltage at which it connects to the electric power transmission network.

The bulk power transmission network will move the power long distances, sometimes across international boundaries, until it reaches its wholesale customer (usually the company that owns the local electric power distribution network).

On arrival at a substation, the power will be stepped down from a transmission level voltage to a distribution level voltage. As it exits the substation, it enters the distribution wiring. Finally, upon arrival at the service location, the power is stepped down again from the distribution voltage to the required service voltage(s).

Early electric energy was produced near the device or service requiring that energy. In the 1880s, electricity competed with steam, hydraulics, and especially (coal gas). Coal gas was first produced on customer’s premises but later evolved into gasification plants that enjoyed .In the industrialized world, cities had networks of piped gas, used for lighting. But gas lamps produced poor light, wasted heat, made rooms hot and smoky, and gave off hydrogen and carbon monoxide. In the 1880s electric lighting soon became advantageous compared to gas lighting.

Electric utility companies took advantage of economies of scale and moved to centralized power generation, distribution, and system management. With long distance power transmission it became possible to interconnect stations to balance load and improve load factors.

VOLTAGE AND PHASE

Grids are designed to supply voltages at largely constant amplitudes. This has to be achieved with varying demand, variable reactive power (reactive) loads, and even nonlinear loads, with electricity provided by generators and distribution and transmission equipment that are not perfectly reliable.

In a synchronous grid all the generators are connected in parallel and run not only at the same Utility frequency but also at the same Phase waves (phase). For steam powered generators, each generator is maintained in this state by a local Governor device(governor) that regulates the driving torque by controlling the steam supply to the turbine driving it. Generation and consumption must be balanced across the entire grid, because energy is consumed almost instantaneously as it is produced. Energy is stored in the immediate short term by the rotational kinetic energy of the generators.

Although an entire grid runs at the same frequency, normally only in very small grids is the frequency fixed. More typically, the frequency of the grid is designed to vary slightly by 1 percent or so depending on the load on the grid. When the grid is very heavily loaded, the frequency slows, and governors adjust their generators so that more power is output (droop speed control). When the grid is lightly loaded the grid frequency runs above the nominal frequency, and this is taken as an indication by Automatic Generation Control systems across the network that generators should reduce their output.

In addition, there's often central control, which can change the parameters of the AGC systems over timescales of a minute or longer to further adjust the regional network flows and the operating frequency of the grid. The structure, or "(Network topology)" of a grid can vary depending on the constraints of budget, requirements for system reliability, and the load and generation characteristics. The physical layout is often forced by what land is available and its geology. Distribution networks are divided into two types, radial or network.

WIDE AREA SYNCHRONOUS GRID

A wide area synchronous grid or "interconnection" is a group of distribution areas all operating with alternating current (AC) frequencies synchronized so that peaks occur at the same time. This allows transmission of AC power throughout the area, connecting a large number of electricity generators and consumers and potentially enabling more efficient electricity markets and redundant generation.

A large failure in one part of the grid - unless quickly compensated for - can cause current to re-route itself to flow from the remaining generators to consumers over transmission lines of insufficient capacity, causing further failures. One downside to a widely connected grid is thus the possibility of cascading failure and widespread power outage. A central authority is usually designated to facilitate communication and develop protocols to maintain a stable grid. For example, the gained binding powers in the. Some areas, for example rural communities, do not operate on a large grid, relying instead on local diesel generators.

High-voltage direct current lines or variable-frequency transformers can be used to connect two alternating current interconnection networks which are not necessarily synchronized with each other. This provides the benefit of interconnection without the need to synchronize an even wider area.

REDUNDANCY AND DEFINING "GRID"

A town is only said to have achieved grid connection when it is connected to several redundant sources, generally involving long-distance transmission. This redundancy is limited, Existing national or regional grids simply provide the interconnection of facilities to utilize whatever redundancy is available. The exact stage of development at which the supply structure becomes a "grid" is arbitrary. Similarly, the term "national grid" is something of an anachronism in many parts of the world, as transmission cables now frequently cross national boundaries. The terms "distribution grid" for local connections and "transmission grid" for long-distance transmissions are therefore preferred, but "national grid" is often still used for the overall structure.

INTERCONNECTED GRID

Electric utilities across regions are many times interconnected for improved economy and reliability. Interconnections allow for economies of scale, allowing energy to be purchased from large, efficient sources. Utilities can draw power from generator reserves from a different region in order to ensure continuing, reliable power and diversify their loads. Interconnection also allows regions to have access to cheap bulk energy by receiving power from different sources. For example, one region may be producing cheap hydro power during high water seasons, but in low water seasons, another area may be producing cheaper power through wind, allowing both regions to access cheaper energy sources from one another during different times of the year. Neighboring utilities also help others to maintain the overall system frequency and also help manage tie transfers between utility regions.

AGING INFRASTRUCTURE

Despite the novel institutional arrangements and network designs of the electrical grid, its power delivery infrastructures suffer aging across the developed world. Contributing factors to the current state of the electric grid and its consequences include:

Aging equipment – older equipment has higher failure rates, leading to Power outage customer interruption rates affecting the economy and society; also, older assets and facilities lead to higher inspection Maintenance, repair, and operations maintenance costs and further Maintenance, repair, and operations and Renovation restoration costs.

FUTURE TRENDS

SMART GRID

The electrical grid is expected to evolve to a new grid paradigm: the smart grid, an enhancement of the 20th century electrical grid. The traditional electrical grids are generally used to carry power from a few central generators to a large number of users or customers. In contrast, the new emerging smart grid uses two-way flows of electricity and information to create an automated and distributed advanced energy delivery network. Many research projects have been conducted to explore the concept of smart grid. According to a newest survey on smart grid,

The infrastructure system is the energy, information, and communication infrastructure underlying of the smart grid that supports

1. advanced electricity generation, delivery, and consumption;
2. Advanced information metering, monitoring, and management; and
3. advanced communication technologies.

In the transition from the conventional power grid to smart grid, we will replace a physical infrastructure with a digital one. The needs and changes present the power industry with one of the biggest challenges it has ever faced.

A smart grid would allow the power industry to observe and control parts of the system at higher resolution in time and space

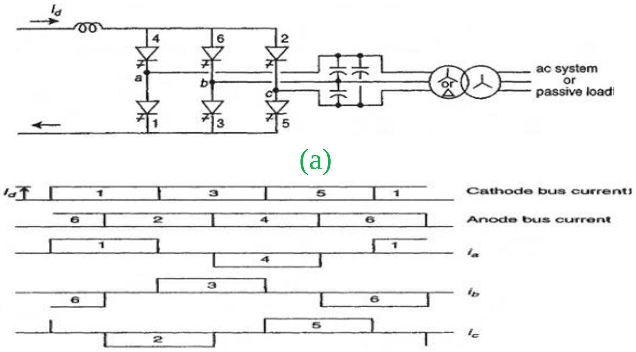
It would allow for customers to obtain cheaper, greener, less intrusive, more reliable and higher quality power from the grid. The legacy grid did not allow for real time information to be relayed from the grid, so one of the main purposes of the smart grid would be to allow real time information to be received and sent from and to various parts of the grid to make operation as efficient and seamless as possible. It would allow us to manage logistics of the grid and view consequences that arise from its operation on a time scale with high resolution; from high-frequency switching devices on a microsecond scale, to wind and solar output variations on a minute scale, to the future effects of the carbon emissions generated by power production on a decade scale.

SELF-COMMUTATING CONVERSION

The present self-commutating HVDC technology favours the use of IGBT-based VSC, combined with high-frequency sub-cycle switching carried out by PWM. Although the IGBT switch can also be used in CSC, a diode is needed in series with the IGBT in this case to provide sufficient reverse voltage withstand capability and the extra diode increases the converter losses. Multi-level conversion, unlike PWM, uses fundamental frequency switching and can, therefore, be designed with thyristor-type switching devices(such as the GTO and IGCT). In particular, the IGCT is an ideal switch for HVDC application due to its higher voltage and current ratings, high reverse voltage blocking capability(without the need for the series diode) and low snubber requirements. Most of this chapter is concerned with the basic structure and operating principles of self-commutating VSC.

Current Source Conversion

CSC requires a large inductance on the DC side to make the DC current well defined and slow to change. The AC side voltage is then the variable directly controlled by the conversion process. Since the AC system has significant line or load inductance, line-to-line capacitors must be placed on the AC side of the converter. The switches must block voltages of both polarities, but they are only required to conduct current in one direction.



(a)

(b)

Figure 3.1CSC: (a) circuit diagram; (b) current waveforms

Similar to the VSC, the CSC is capable of operating with leading power factor. Also theself-commutation of the valves permits the converter to operate as an inverter into a passive,as well as an active, load or system. The introduction of self-commutation eliminates practically the main disadvantages ofLCC described in Section 4.3 and makes the robust thyristor-based conversion an alternativeworth considering for HVDC application.

Application to VSC

The reinjection principle has been described in with reference to the linecommutatedCSC (both for the single and double bridge configurations). When appliedto VSC, the individual bridges need to be supplied, via the common or neutral point, byan appropriate voltage waveform derived from the DC voltage source and varying at sixtimes the fundamental frequency. In the ideal case, the addition of the reinjection and mainbridge voltages should produce a waveform that, when added to that of the second bridge,will achieve complete cancellation of the harmonic content at the converter system outputterminals.

Application to CSC

CSC can be viewed as the dual of VSC: that is, current waveforms in CSC are dual tovoltage waveforms in VSC. CSC requires switching devices of different characteristicsfrom those of VSC. The latter requires asymmetrical switches (with unidirectional voltageblocking and bidirectional current capability), while CSC requires symmetrical switches(with bidirectional voltage blocking and unidirectional current capability). Thus the IGBTcannot by itself be used in CSC; a diode connected in series with the IGBT can solve theproblem, but at the expense of considerable extra power losses. The symmetrical GTO andIGCT types are more appropriate switching devices, due to the relatively low switchingfrequency of the CSC.The CSC alternative also has some advantages, such as the following:

- Better current control. The short-term overcurrent protection is inherent by the presenceof the DC side inductor, while the long-term protection is achieved by the current controlloop. Internal faults, however, may still require fast interruption.
- The large power inductor, providing the DC bus energy storage, is simpler and more reliable than the large capacitor of the VSC.
- It is better suited to higher power devices, such as the IGCT, which can block voltagein either direction but conduct current only in the forward direction.
- Soft switching is easier to provide.

The reactive power consumption, although possibly higherinitially, is partially or totally eliminated following the disturbance, with the result of considerabledynamic overvoltage regulation. Theregulation (dynamic) overvoltages are more significant at the rectifier end of thelink. At both terminals the effective impedance angle is as important in determining theovervoltages as is the magnitude of the impedance. For links from hydro sources, the increaseof frequency following load rejection will produce even higher dynamic overvoltages. Thisis an unacceptable situation for local consumers and must be allowed for in the insulationcoordination of the converter station.In practice, transformers start to saturate at typically 1.2 to 1.25 pu AC voltage and thefundamental frequency overvoltage will therefore be a little lower, with some distortion.Single line-to-ground faults are also a source of dynamic overvoltages on the other phasesor pole, due to mutual coupling between phases.Following a voltage drop in the AC network, the initial effect is a fall in power. Thepower controller of the DC link then increases the current reference to try and restore theordered power; the extra current increases the reactive demand and tends to reduce the ACsystem voltage further. With very weak AC systems this could lead to voltage collapse;however, power controllers always have limits built in to avoid excessive action.

Active and Reactive Power Coordination

The degree of DC power modulation which can be achieved is restricted by terminal reactivepower constraint. With only current or power modulation, an increase in active powertransfer will be accompanied by a larger increase in terminal reactive power requirementsand this effect is particularly noticeable during severe system disturbances. The reactivepower variations can cause current control mode transitions between the rectifier and inverterends, and hence DC changes equal to the DC system margin current.Coordination between the active and reactive power modulation can be achieved by DCsystem voltage modulation. An increase in DC voltage will increase the DC power transferas well as the power factor at both terminals, and hence decrease the reactive consumptionas a percentage of active power transmitted.

Transient Stabilization of AC Systems

Where system disturbances result in the reduction of transmission capability, the generatingsource will usually accelerate. Remote sources may decelerate as load exceeds generationas a result of the fault which decreases power into that area. When the fault is cleared, thegeneration and the remaining transmission experience a transient swing which may lead toinstability. In particular, long fault clearance times can cause a loss of synchronism.If the loss of synchronism is irrelevant, as in the case of an HVDC link connectinggeneration to load areas, it is advantageous to increase the sending end DC link power inthe post-fault period in response to the increase of generator speed. This action will removeenergy from the generator, reduce its speed, and thus reduce the angular displacementbetween the generator and the AC receiving system. An appropriate magnitude of themodulation applied for this purpose is in the range of 20 to 40% of the DC link rating.

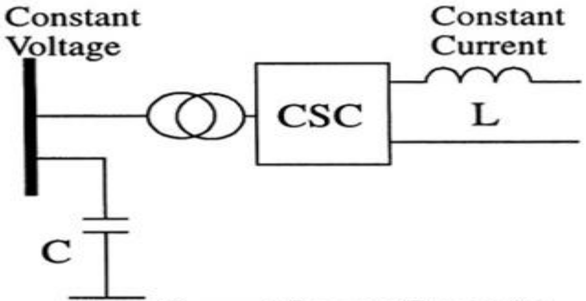
Somesystems have been designed with temporary overload limits as high as 65 %. In other caseseven higher modulation limits have been utilized after taking into account the AC systempower transfer need, the AC voltage support (VAR) capability and the DC system designratings. Similarly, for receiving end phase angle or speed changes, DC link power can becontrolled to correct this condition within the limits imposed by the controllability of thereceiving end phase angle, the DC link capability, and the energy that may be taken fromthe generation source.

Harmonic Cross-Modulation Across the DC Link

The numerous problems of frequency cross-modulation encountered by early HVDCschemes motivated a report on the subject by a Working Group of CIGRE SC-14 andthe material used in this section comes from that report. The presence of low-orderuncharacteristic harmonics has been an important issue in early LCC schemes with relativelylow SCRs, by exciting converter transformer asymmetrical saturation, which often leads toharmonic instability.The traditional definition of resonance is still commonly used with reference to either the ACor DC sides of the converter independently from each other. This sort of resonance is welldefined, being the frequency at which the capacitive and inductive reactance of the circuitimpedance are equal. At the resonant frequency, a parallel resonance has a high impedanceand a series resonance a low impedance.Moreover, when the AC and DC systems are interconnected by a static converter, thesystem impedances interact via the converter characteristics to create entirely differentresonant frequencies.

CURRENT SOURCE CONVERTERS (CSC)

Since the basics of 6-pulse bridge CSC converter theory are already well documented in other books, this chapter will be kept brief and isincluded for the sake of completeness only so that the book is self-contained.Moreover, the terminology that will be employed in later chapterswill be introduced here.To consider the theoretical analysis of a conventional 6-pulse bridge, the following assumptions are made:DC current is constant (i.e. the smoothing reactor is infinite),Valves are ideal switches, andAC system is infinitely strong (i.e. the 3 phase emfs are balanced andperfectly sinusoidal).



Current Source Converter

Individual Phase Control (IPC) Unit

In this type of GFU (now obsolete), the firing pulses are directly derivedfrom the zero crossover points of the commutation voltage. Consequently,the firing pulses are vulnerable to harmonic pollution on the waveform.Early attempts to use filtering techniques to alleviate some of these problemswere not successful for operation with weak ac systems due to theintroduction of phase shifts. Developments in tracking band-pass filters which derive the fundamental frequency component of the commutationvoltage with no phase shift may be useful in operation with weak ac systems.However, the main disadvantage of IPC systems, which eventuallyled to their demise, was the generation of non-characteristic harmonicswhich caused harmonic instability problems.

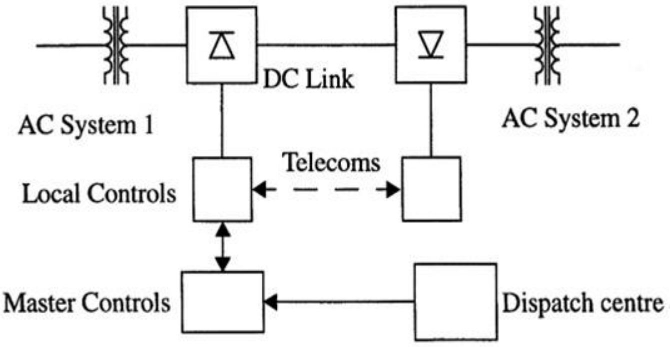
Pulse Phase Control (PPC) Type

In a GFU of this type [4], the dc control voltage resulted in a change to thephase of the VCO output rather than its frequency. The transfer function ofthis type of unit is therefore proportional rather than integral. To ensure thesynchronism of the VCO output frequency with the ac supply frequency, aslower acting frequency error feedback loop is used. This type of GFU doesnot permit the modulation of firing pulses on an individual basis either.The most obvious method was to utilize an independent oscillator at (50or) 60 Hz which could be synchronously locked to the ac commutationvoltage.

This oscillator would then provide the (phasor) reference relationshipto the trigger unit during the perturbation periods, and would use thesteady state periods for locking in step with the system frequency. Theadvantage of this independent oscillator was to provide an ideal (immunizedand clean) sinusoid for synchronizing and timing purposes. Due to its timingstability, it offered the possibility of equi-distant firing pulses [5,7,13]which eliminated the generation of non-characteristic harmonics duringsteady-state operation. This was a prevalent and undesirable feature duringthe use of the earlier Individual Phase Control (IPC) system where the firingpulses were directly coupled to the commutation voltage,There were two possibilities for this independent oscillator:Use of a fixed frequency oscillator (also called the Pulse Phase ControlOscillator (PPCO)) operating at a fixed frequency of 60 Hz. However,since the system frequency actually drifts between say 55-65 Hz due tothe generators used to produce electricity, it was necessary to employ acontrol loop to track the drifting firing angle.

FUNCTIONS OF HVDC CONTROLS

In a typical two-terminal dc link connecting two ac systems,the primary functions of the dc controls are to:Control power flow between the terminals,Protect the equipment against the current/voltage stresses caused byfaults, andStabilize the attached ac systems against any operational mode of the dclink.



The two dc terminals each have their own local controllers. A centralizeddispatch centre will communicate a power order to one of the terminalswhich will act as a Master Controller and has the responsibility to coordinatethe control functions of the dc link. Besides the primary functions, it isdesirable that the dc controls have the following features:

- Limit the maximum dc current.
- Maintain a maximum dc voltage for transmission.
- Minimize reactive power consumption.

PROPOSED SYSTEM

This chapter investigates the interconnection of CSCs to a very weak utility-grid using theconventional vector control in the rotating reference frame. It is shown that the system stabilityis degraded under weak-grid conditions due to the implementation of the PLL. Supplementarycontrollers are proposed and integrated to the outermost control loops of the CSC to alleviate theassociated negative impacts of the PLL.

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The proposed compensators do not alter the dynamiccharacteristics of the conventional vector control, i.e., the PLL, the current, and the voltagecontrol. More importantly, it could be possible for the CSC to inject p.u. of active power at aunity SCR. The small-signal stability analysis and controllers design procedures are presented indetails. The design of the proposed compensators is independent of the conventional vectorcontrol, and hence no extensive coordination and parameters tuning are needed. Time-domainsimulations results are presented to validate the effectiveness of the proposed techniques.

Modeling and Control of the Grid-Connected Current-SourceConverter

The grid-impedance comprises a large inductive part (Lg) inseries with the equivalent resistance of the line (Rg).

$$L_g = \frac{v_g^2}{VA_{sc}}\frac{1}{\omega},$$

$$R_g = \frac{\omega L_g}{XR}$$

A grid-connected CSC is shown in Fig. 4.1. The converter consistsof six switching cells; each comprises an IGBT in serieswith a diode to increase the reverse voltage blocking capability. The pulse-width-modulation (PWM) technique defines theoutput current through a closed-loop control strategy. Theac-side of the CSC is terminated by a capacitive filter toabsorb the switching harmonics from and inject nearly puresinusoidal currents to the grid. The root-mean-square (rms)three-phase terminal voltage of the CSC, whereas is therms three-phase grid voltage. The grid-impedance comprisesa large inductive part in series with the equivalent resistanceof the line .

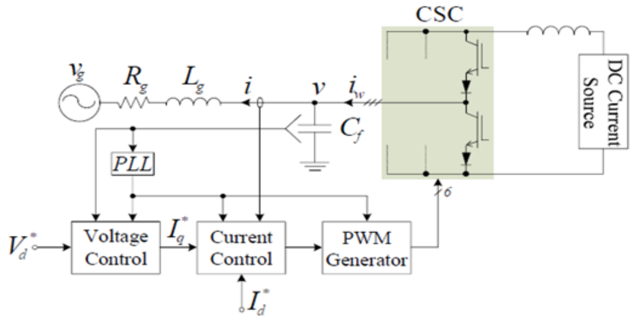

Fig. 4.1.Grid-connected CSC system.

A. Power Circuit Model

The power circuit model of the filter and the grid impedancein the rotating reference frame that rotates by the angular speedis as follows:

$$\bar{i}_w = (sC_f + j\omega C_f)\bar{v} + \bar{i}$$

$$\bar{v} - \bar{v}_g = (R_g + sL_g + j\omega L_g)\bar{i}$$

B. PLL Dynamics

As shown in Fig. 3.1, the vector control is characterized by thePLL to synchronize the CSC to the grid. The detailed structureof the PLL is shown in Fig. 3.2(a). The PCC voltage is decomposedinto the equivalent d- and q-components in the rotatingreference frame. The grid frequency is then estimated by settingthe normalized q-component of the PCC voltage to zero usinga proportional-and-integral (PI) controller. The synchronization angle is obtained by an integrator,and is used in the transformation from the three-phasegrid-frame to the converter d-q reference-frame, and vice versa. Under transient conditions, the angle oscillates toresynchronize the converter with the grid and eventually becomeszero in steady-state conditions.

Referring to Fig. 3.2(b), the measured quantities should be transformed to the converter reference frame whereasthe controller output signals should be retransformedto the grid reference frame to accurately model the influence ofthe PLL on the system dynamics.

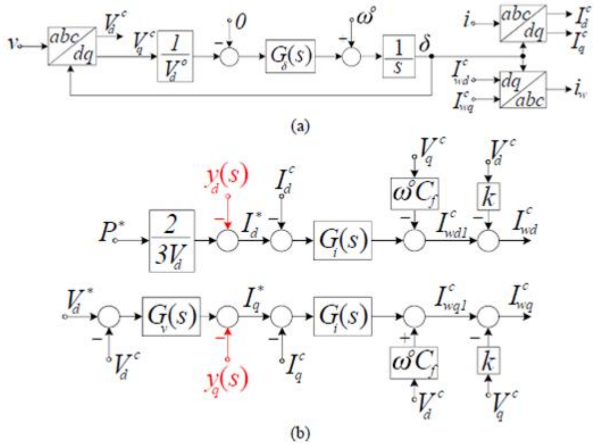

Fig. 4.2.Vector control of the grid-connected CSC. (a) SRF-PLL. (b) Voltage and current control.

SMALL-SIGNAL MODELING OF THE CSC CONNECTED TO WEAK-GRID SYSTEMS

The detailed small-signal modeling of the grid-connectedCSC is presented in this section. The complete system parametersare shown in Appendix A whereas the matrices of thefollowing state-space models are defined in Appendix B. In the following are the state, input, and output matrices,respectively, and are multiplied by the corresponding vectors and represents a small perturbation of the variable.Based on the SyQuest stability criterion, the magnitude of theoutput impedance of the CSC should be as high as possiblein order to preserve the system stability. The compensator signals are designed based on the fact thatthe PLL is the dominant detrimental element in the vector-controlledconverters in weak grid systems.Four states are added to the uncompensated model;three from the proposed compensator and one from the feed-forwardloop.The controller computational delay and the PWM switching are modeled as a dead time.

The dynamics of the current controller in are investigated whenthe dead time is considered in the model, and then is modified. Figure shows the influence of the dead time on the closed-loop transfer function of the current controller. The performance of the current controller with and without the dead time is almostidentical. The bandwidth of the current controller decreases from 400 rad/s to 360 rad/s when atwo-sample delay is considered. The admittance of the current controller, it is notaffected by the two-sample delay as shown in figure. It is clear that the dead time slightlyaffects the inner current control loop. Therefore, the outer loops remain unaffected as thebandwidth of the inner loop is not significantly reduced to accommodate the delay.

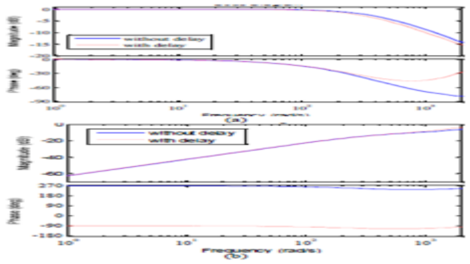

Figure 4.3 Impact of the dead time on the performance of the current controller.

SIMULATION RESULTS

A time-domain simulation model for the grid-connected CSCis built under Matlab/Simulink environment to evaluate the precedingtheoretical analysis and validate the influence of the proposedcompensators.The CSC is rated at 36 MVA whereas avery weak grid is considered at SCR =1.0. The completemodel entities are built using the SimPowerSystem toolbox. TheCSC is simulated using average-model-based blocks. The simulationtype is discrete with a sample time of 50microseconds . To accuratelymodel the influence of the computation and dead time delays, atwo-sample delay is implemented at the output signals of theinner current controllers.

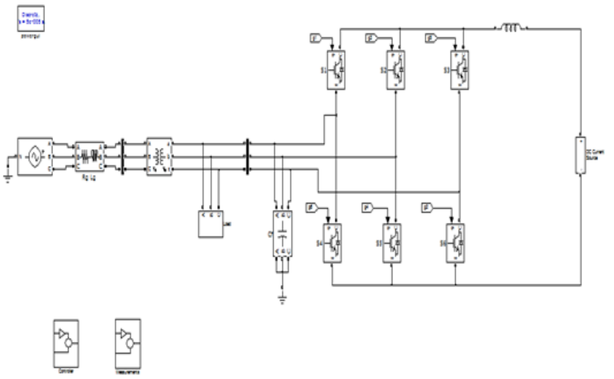

Fig:5.1- simulation diagram of average model of the CSC at SCR=1.0.

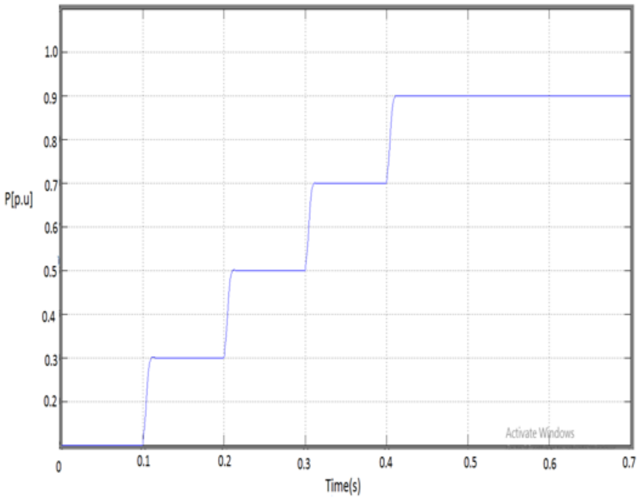

Fig:5.2(a)Average model of the CSC at SCR=1.0. (a) Active power.

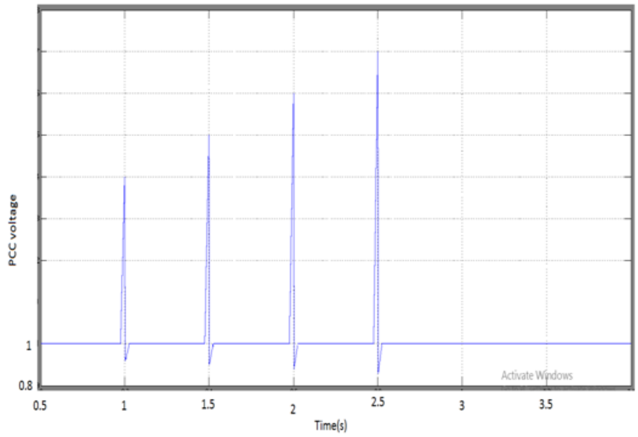

Fig:5.2(b)Average model of the CSC at SCR=1.0. (b) PCCvoltage.

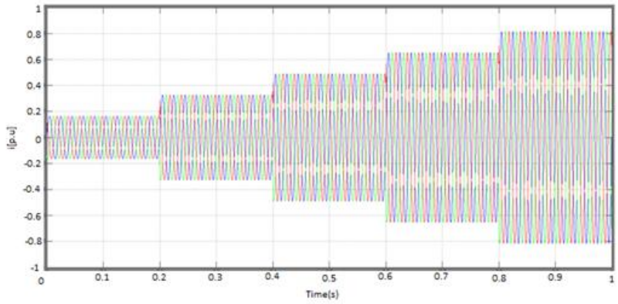

Fig:5.2(c)Average model of the CSC at SCR=1.0. (c) Injected current to the grid.

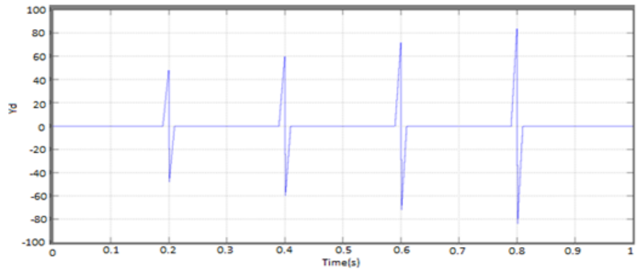

Fig:5.2(d)Average model of the CSC at SCR=1.0. (d)Compensation signals.

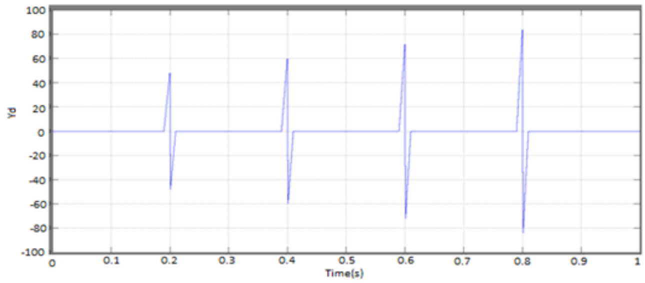

Fig:5.2(e)Average model of the CSC at SCR=1.0. (e) Compensation signals.

The proposed compensatorsare all implemented in the time-domain model, and thesystem performance is investigated in Fig. 4.1. Fig. 4.2(a) showsthe injected active power to the grid.Themagnitude of the PCC voltage is shown in Fig. 4.2(b) where aunity p.u. value is maintained under different loading conditionsby injecting the corresponding reactive power to the grid. Theinjected current to the grid is shown in Fig. 4.2(c). As mentionedearlier, the compensation signals have a zero steady-statevalue and hence they do not alter the accuracy of the controlledparameters as shown in Fig. 4.2(d)& (e).A switching model of the grid-connected CSC system isbuilt under Matlab/Simulink for further investigations. The PWM technique has been implemented to obtain theswitching patterns for IGBTs.

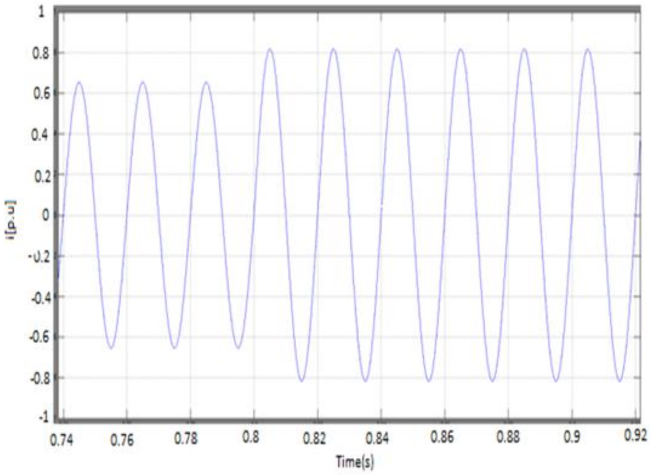

Fig:5.3(a)Switching model of the CSC at SCR =1.0. (a) Injected current.

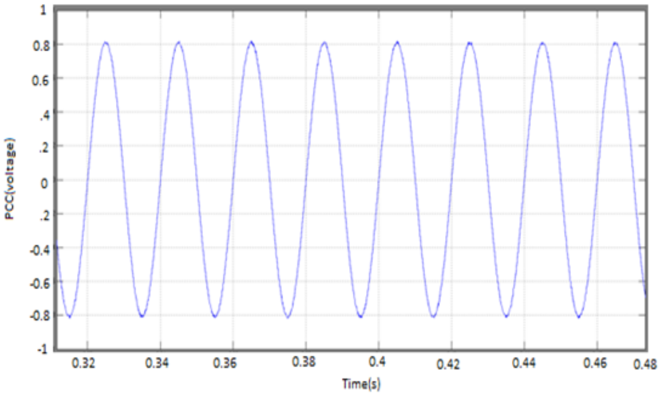

Fig:5.3(b)Switching model of the CSC at SCR =1.0. (b) PCC voltage.

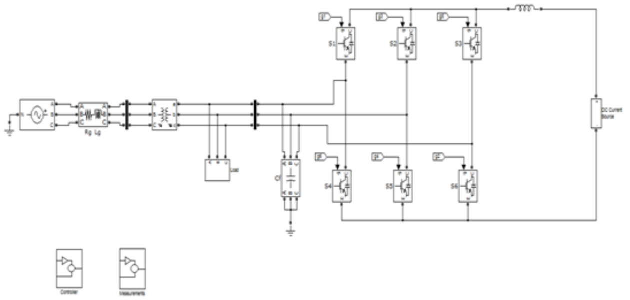

Fig:5.4- Influence of the proposed compensators on the CSC controllers SCR=1.0(compensated system).

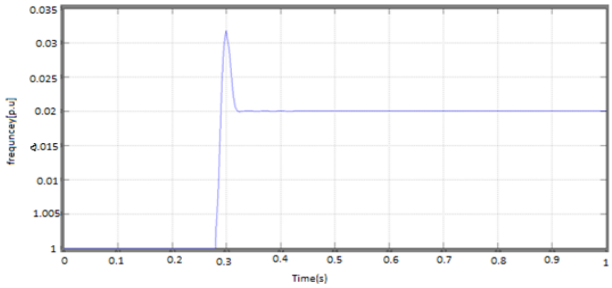

Fig:5.5(a)Influence of the proposed compensators on the CSC controllers SCR=1.0(compensated system).(a) PLL response.

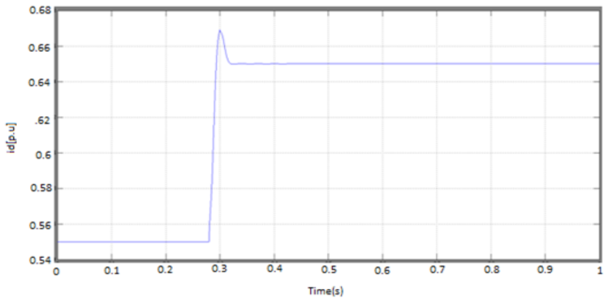

Fig:5.5(b)Influence of the proposed compensators on the CSC controllers SCR=1.0(compensated system).(b) Current response (d-channel).

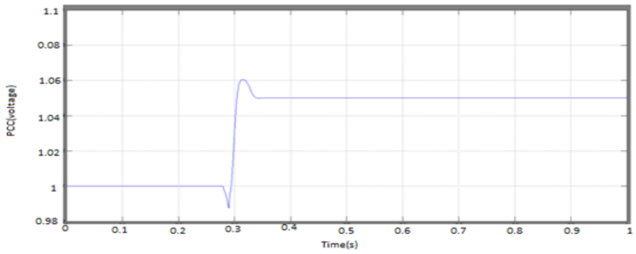

Fig:5.5(c)Influence of the proposed compensators on the CSC controllers SCR=1.0(compensated system).(c) Voltage response.

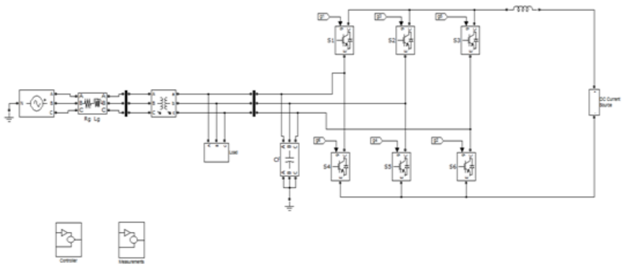

Fig:5.6- Influence of the proposed compensators on the CSC controllers SCR=1.0(uncompensated system).

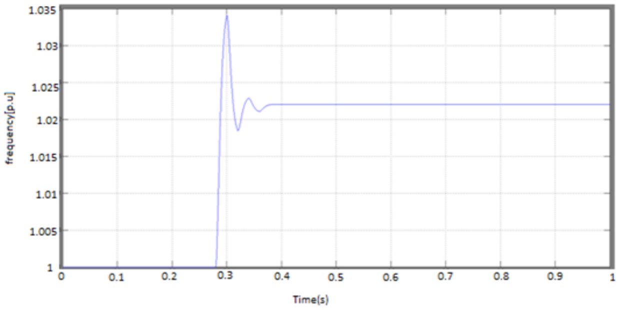

Fig:5.7(a)Influence of the proposed compensators on the CSC controllers SCR=1.0(uncompensated system).(a) PLL response.

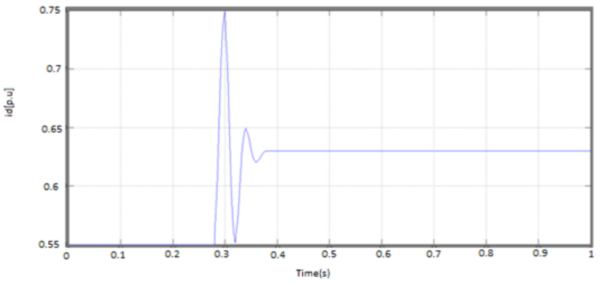

Fig:5.7(b)Influence of the proposed compensators on the CSC controllers SCR=1.0(uncompensated system).(b) Current response (d-channel).

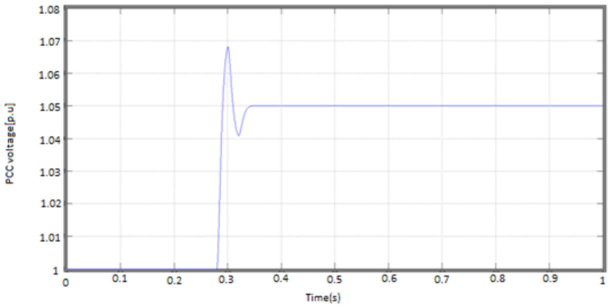

Fig:5.7(c)Influence of the proposed compensators on the CSC controllers SCR=1.0(uncompensated system).Voltage response.

CONCLUSION

Active compensation techniques have been proposed to stabilizea grid-connected CSC at SCR=1.0. Unlike the uncompensatedconverter where the system becomes unstable beyond, the full rated active power injection has beenachieved with the proposed techniques. A small-signal state spacemodel of the entire system is developed to investigate thesystem dynamics under the weak grid conditions.

The proposedcompensators have the following features. 1) They are simpleand can be easily designed using linear analysis tools. 2) Theydo not influence the steady-state operation of the CSC. 3) Theyhave no effect on the dynamics of the PLL, the current, and thevoltage controllers; therefore, the proposed compensators canbe augmented with the standard vector controller without majorchanges in the controller structure and parameters. 4) They arerobust under different operating conditions. 5) No extra voltageor current sensors are needed to implement the proposed compensators.Time-domain simulations have been provided to validatethe developed analytical models and show the effectivenessof the proposed techniques.

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