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DFIG CONVERTER CONTROLLERS USED IN WIND FARMS TO IMPROVE POWER TRANSFER CAPABILITY OVER LONG DISTANCES

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Abstract: To address the challenges of global warming resulting worldwide climate change leading to devastating calamities and posing basic threat to all living things on earth, modern day research is rightfully directed towards clean sources of green energy. Wind Power is the fastest growing environmental friendly emission free green source of energy. Effective long distance power transfer capability of the system is warranted due to locational disadvantages of availability of some Wind Power sites situated in remote areas away from load centre and even some best sites available offshore. This paper presents the study of doubly fed induction generators (DFIG) converter controllers integrated to flexible alternating current transmission system (FACTS) to improve power transfer capability of Wind farms over long distances.

I. INTRODUCTION

In the modern world, the gradually increasing electric power demand arising out of our power dependent life style in every sphere is necessitating generation of more electric power throughout the globe. To meet the requirement of ever increasing power demand, new power plants are being established in a very fast pace and in some cases the capacity of the existing plants are increased. It is however scientifically established that power sector is significantly contributing towards global warming which is directly impacting climate change throughout the world due to burning of fossil fuels for generation of electricity and polluting the atmosphere by emission of greenhouse gases. Therefore there is a definite need to look into various sources of clean green energy. Wind source has a distinct edge over other available renewable sources of clean energy such as solar power, hydro power, ocean wave power and so on. With the development of technology, electricity generation using wind source has drawn an increased attention throughout the world. More wind power integrated into the system causes power quality and stability problems. Therefore power utilities are developing strict grid codes which are to be satisfied by the producers of wind power. Voltage control and reactive range potential, frequency control capability and fault ride through ability are among the major requirements specified in the grid codes [1]. Due to the intermittent feature of the wind, power quality and stability problems are faced. This problem becomes noticeable, especially, when the amount of wind power integrated to the system is sufficiently large. In view of the variable speed operation potential, DFIG is becoming popular generation of wind power. Control of the voltage of the DFIG wind farm has been identified as the latest challenge with the present requirements of grid code. Variations of output voltage of a wind farm occur due to the wind gusts and frequent gradual wind speed variations. Also wind power plants are vulnerable during some transient states as well. Sub synchronous resonance (SSR) is a major challenge in long distance power transfer in wind farms and its damping is essential for effective system stability and power transfer. The wide use of wind generation warrants that the wind farms should be able to contribute to network support like the conventional synchronous generators. DFIG is a wound rotor induction motor with rotor insertion. The speed of the DFIG can be controlled by inserting changeable voltage of slip frequency to the machine rotor. It has become popular in wind farms, since it enables maximum energy due to its ability of operation in variable speed.

This paper presents the study of sub-synchronous resonance (SSR) damping [2], [3]. [4], [5],[8] using the rotor side converter (RSC) and grid side converter (GSC) controllers of the DFIG.

The objective is to design a simple commensurable SSR damping controller (SSRDC) by properly choosing an optimum input control signal (ICS) to the SSRDC so that the SSR mode becomes stable without decreasing or destabilizing the other modes of the system. Moreover, an optimum point within the RSC and GSC controllers to inject the SSRDC is identified. Three different signals are tested as capable ICSs including line real power, rotor speed and voltage over the series capacitor and an optimum ICS is established using residue-based analysis and root-locus method. Matlab / Simulink is used as a tool for modeling and design [3], [5], [6], [7], [9] of the SSRDC and PSCAD/EMTDC is used to perform time-domain simulation for design process validation.

II. DFIG CONVERTER CONTROLLERS

An additional SSR damping controller (SSRDC) [3] either on the grid side converter (GSC) or on the rotor side converter (RSC) is used to damp SSR operating on a single input control signal (ICS) as illustrated in Figure 2.1 and Figure 2.2. The SSRDC block is represented in Figure 2.3, which is based on proportional gain K_{SSR} and washout filter. The value of the K_{SSR} for each ICS is obtained using root-locus method such that 6% damping ratio is obtained for the SSR mode. The 6% damping ratio is chosen arbitrarily, but the procedure can be used for any desired value of damping ratio. Moreover, a washout filter, which is a high pass filter, is included in the SSRDC block to eliminate the effect of the SSRDC on the steady-state operating condition. Usually the value of the washout filter time constant *Tw* is chosen to be between 5 to10 secs. In this work, *Tw* = 5 *sec.* [4] There are a variety of options for the ICS, as shown in Figure 2.1 and Figure 2.2. In this study, rotor speed ω_r, transmission line real power P_L, and voltage across the series compensation V_C are examined, and the optimum ICS is identified with the help of residue based analysis and root-locus diagrams.

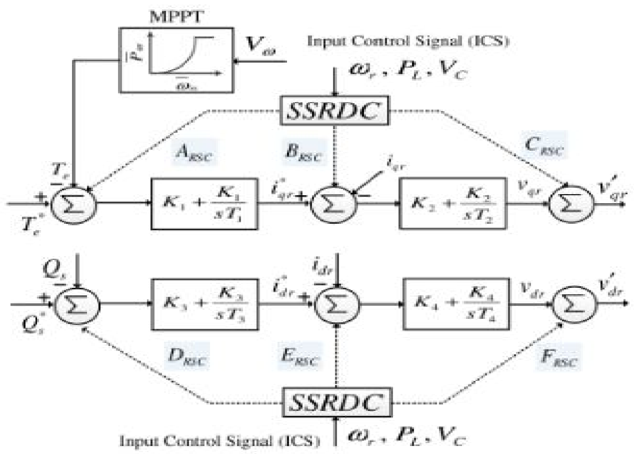

Figure 2.1: RSC controllers

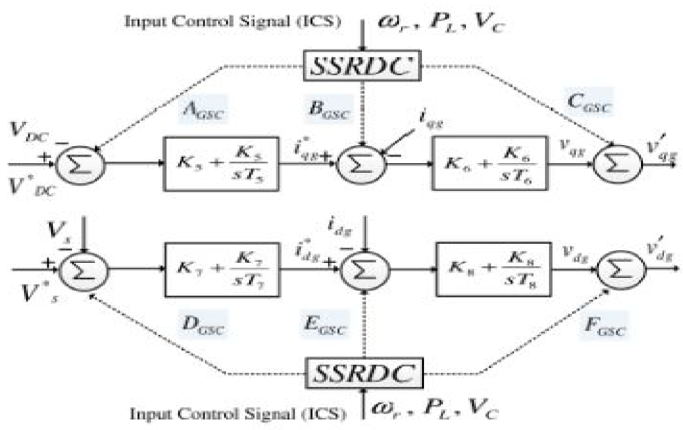

Figure 2.2: GSC controllers

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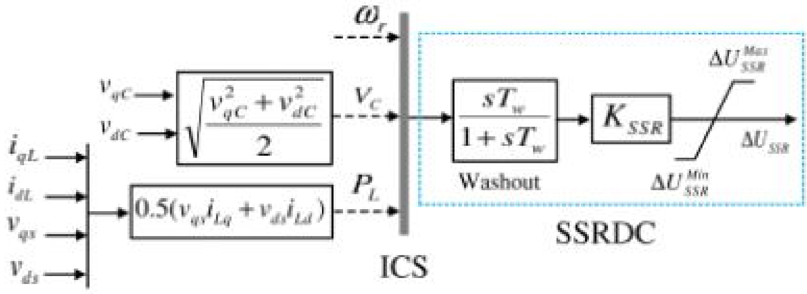

Figure 2.3: SSR damping controller block diagram

1. ICS AND CONVERTER SELECTION FOR SSRDC DESIGN AND CONTROLLABILITY

Using residue-based analysis and root-locus method, an optimum input control signal (ICS) to the SSRDC is introduced. The optimum ICS should enable the SSRDC to damp the SSR without decreasing or destabilizing the other system modes. The SSRDC can be inserted at different points of the RSC and GSC controllers, identified as A_{RSC} to F_{RSC} and A_{GSC} to F_{GSC} in Figure 2.1 and Figure 2.2. These insertion points are examined to find out where the SSRDC could be introduced. Controllability [3], [7] plays an important role in the design of control systems in state-space. In a controllable system, it is possible to transfer the system at time t_0 from any initial state X_{t0} to any other state using an unconstrained control vector in a finite interval of time. Consider the state-space equations for a n^{th}- order linearized system as follows:

$$X = AX + BU \qquad (3.1)$$

This system is completely state controllable, if the matrix given in Eq. 3.3 is of rank n [5].

$$Co = [B\ AB\ ...\ A^{n-1}B] \qquad (3.2)$$

Where Co is called the controllability matrix.

The controllability [7], [8], [9] condition of the studied system is tested, and found the system is completely controllable. The designed SSRDC is a simple proportional gain. Therefore, if the system is completely controllable, then the variations of the designed SSRDC gain, K_{ssr}, will affect all modes of the system. This means that while trying to make the SSR mode stable using the proportional SSRDC, this gain will influence other system modes by making them to move either to the right or to the left in the root-locus diagram.

III. SSRDC IMPLEMENTED IN RSC CONTROLLERS

Figure 4.1 show the dynamic performance of the transmission line real power P_L when the SSRDC is implemented at RSC [3]. Figures 4.1- a through -c show that as soon as the compensation level increases from 50% to 55% at t = 0.5 s, regardless of which ICS is used, the sub-synchronous and super-synchronous oscillations appear in the transmission line real power, and these oscillations damp out in less than 0.25 s, but another oscillations start to appear in the system dynamics making the wind farm unstable. The frequency of these oscillations is in range of electro-mechanical mode ($\lambda_{5,6}$).Indeed, the reason for the instability of the wind farm in this case is not the SSR mode, but it is the unstable electro-mechanical mode. The root-locus figures results [3] clearly show that increasing the SSR gain, to make the SSR mode stable, causes the electro-mechanical mode to go unstable. Therefore, in spite of what kind of ICS is used, the SSRDC cannot be implemented at RSC controllers.

3. SSRDC IMPLEMENTED IN GSC CONTROLLERS

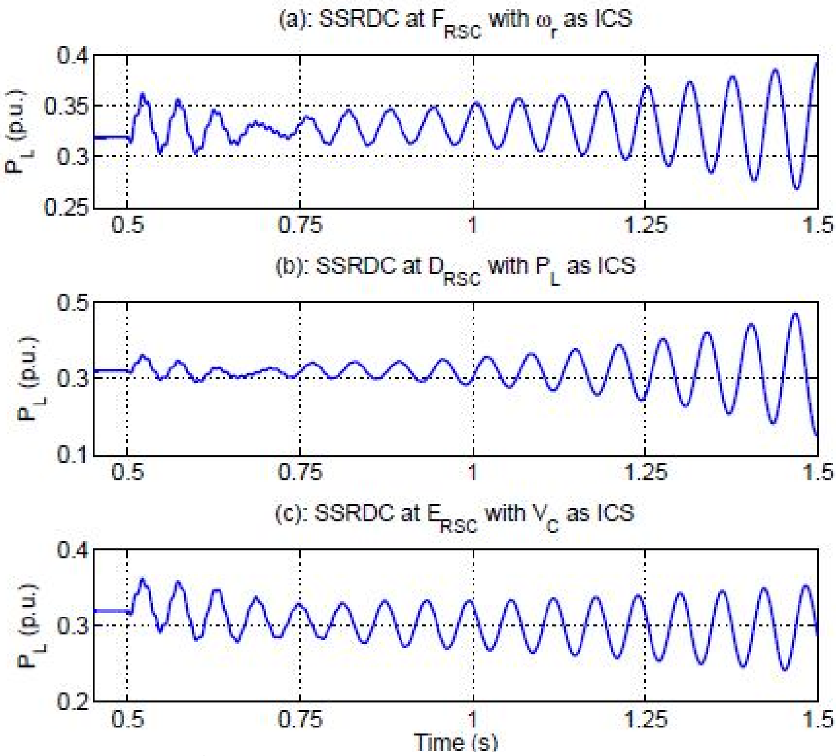

Figure 4.1: Dynamic response of the transmission line real power P when the SSRDC is implemented at RSC

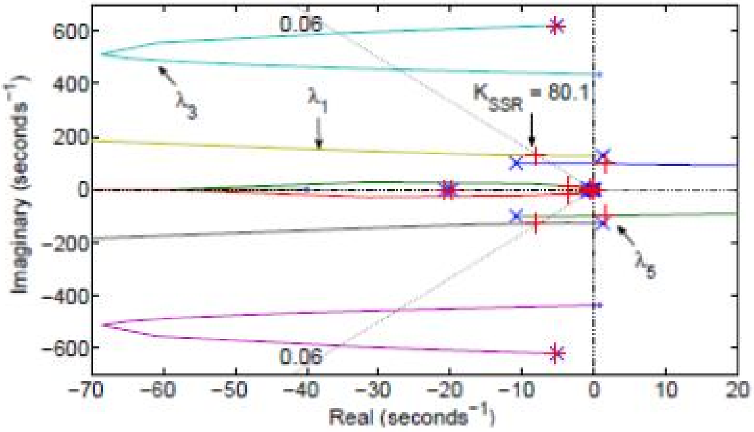

Figure 4.2: Root locus diagram with V_C as ICS with SSRDC implemented in RSC controller at point E_{RSC}.

Figures 4.3 -a and -b show the dynamic performance of the transmission line real power P_L when the SSRDC is implemented at GSC with ω_r and P_L as ICSs. Figure 4.3 -a and -b show that as soon as the compensation level increases from 50% to 55% at $t = 0.5$ s, the sub-synchronous and super-synchronous oscillations appear in the transmission line real power, but only the former damps out in less than 0.25 s, while the latter is sustained in the system and makes the wind farm unstable.

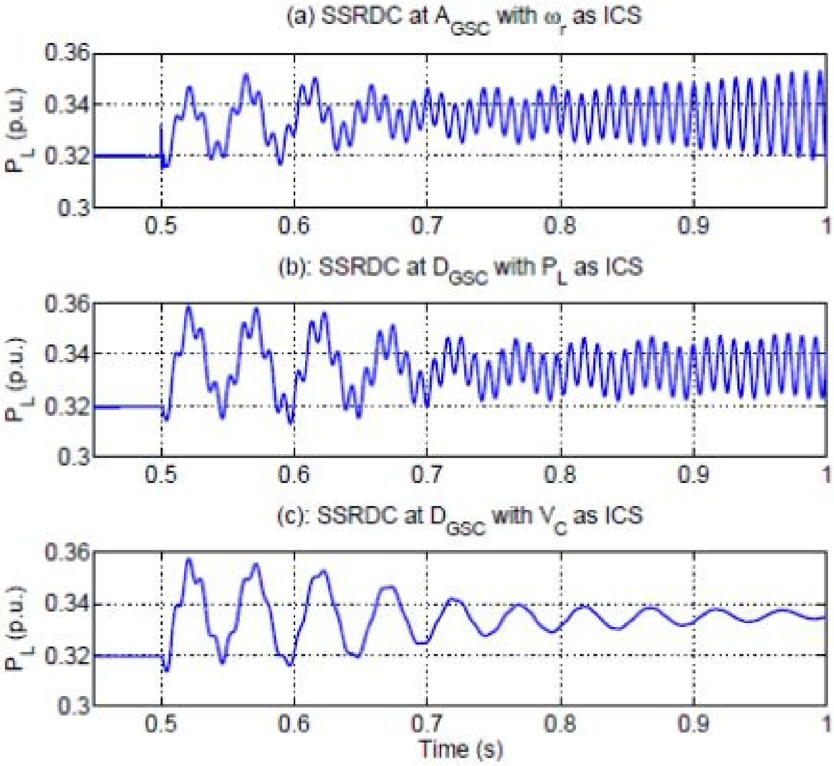

Figure 4.3: Dynamic response of the transmission line real power PL when the SSRDC is implemented at GSC

In fact, the reason for the instability of the wind farm, when variables ω*r* and P_L are used as ICS, is not the SSR mode, but it is the SupSR mode. Study of root-locus results [3] clearly show that by increasing the SSR gain to make the SSR mode stable, the SupSR mode goes unstable. Therefore, ω*r* and P_L cannot be used as ICSs, even when the SSRDC is installed at GSC controllers. Using V_C as ICS with SSRDC implemented at GSC controllers, on the other hand, can stabilize the wind farm, as illustrated in Figure 4.3.

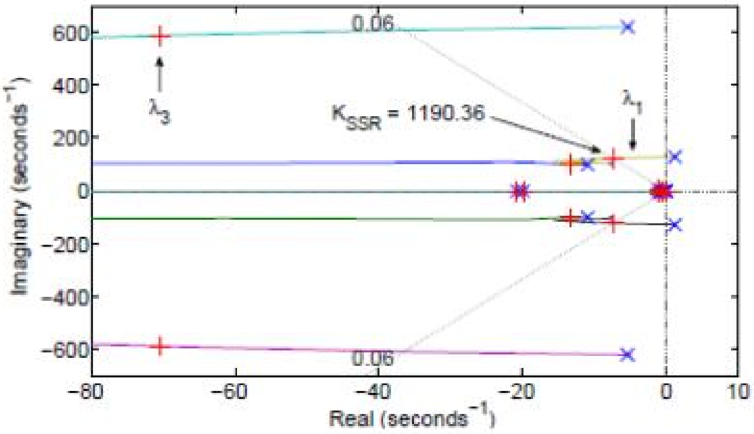

Figure 4.4: Root locus diagram with V_C as ICS with SSRDC implemented in GSC controller at point A_{GSC}

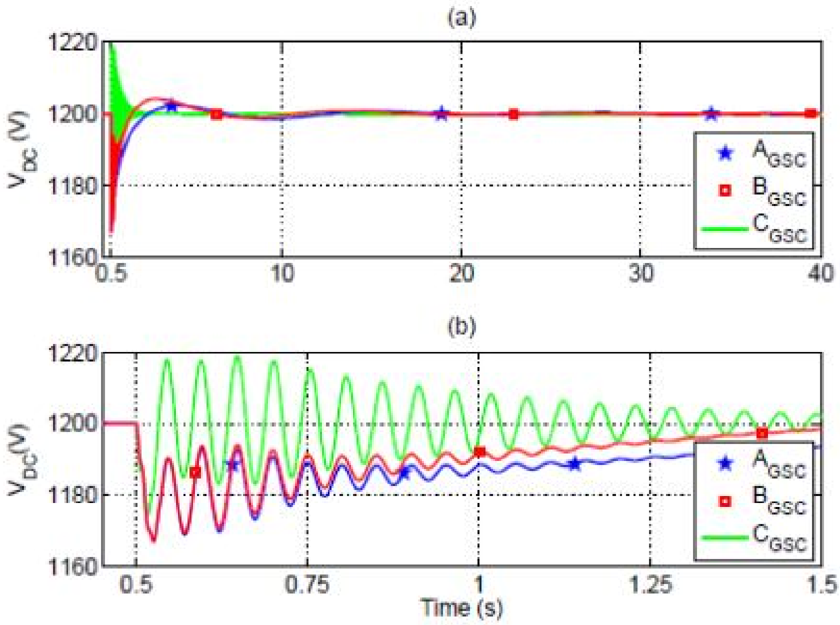

Figure 4.5: Dynamic response of the DC link voltage when SSRDC is implemented A_{GSC}, B_{GSC}, and C_{GSC}. (a) Simulation time from t = 0.5 s to t = 40 s. (b) Simulation time from t = 0.45 s to t = 1.5 s.

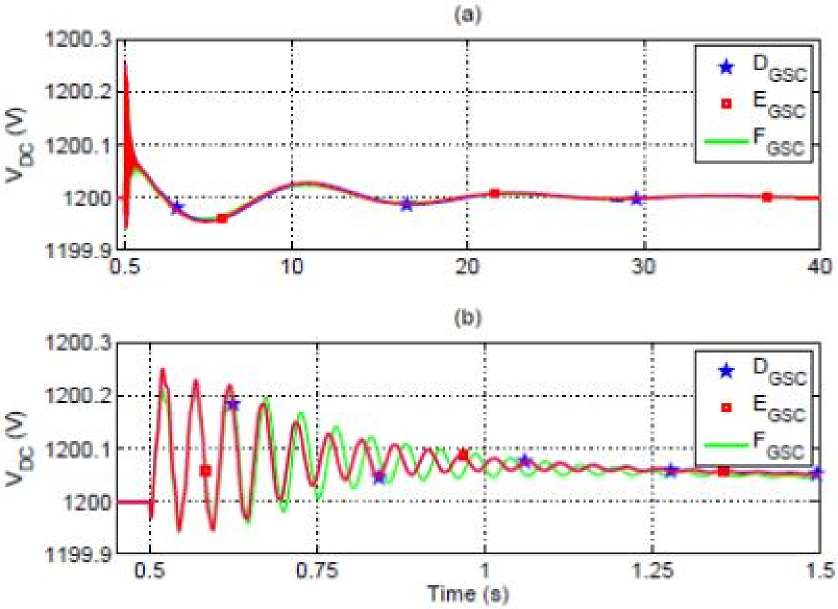

Figure 4.6: Dynamic response of the DC link voltage when SSRDC is implemented at D_{GSC}, E_{GSC}, and F_{GSC}. (a) Simulation time from t = 0.5 s to t = 40 s. (b) Simulation time from t = 0.45 s to t = 1.5 s.

Root locus diagram with V_C as ICS with SSRDC implemented in GSC controller [3] at point A_{GSC} is depicted in Fig 4.4, dynamic response of the DC link voltage when SSRDC is implemented A_{GSC}, B_{GSC}, and C_{GSC}. (a) Simulation time from *t* = 0.5 *s* to *t* = 40 *s*. (b) Simulation time from *t* = 0.45 *s* to *t* = 1.5 *s* [3] depicted in Fig 4.5 and dynamic response of the DC link voltage when SSRDC is implemented [3]at D_{GSC}, E_{GSC}, and F_{GSC}. (a) Simulation time from *t* = 0.5 *s* to *t* = 40 *s*. (b) Simulation time from *t* = 0.45 *s* to *t* = 1.5 *s* depicted in Fig 4.6.

IV. TIME-DOMAIN SIMULATION OF THE WIND FARM WITH SSRDC

To validate the results of Section, the time-domain simulation of system shown in Figure 2.1 with the SSRDC is presented [3]. PSCAD/EMTDC is used to perform the simulations. In the entire simulation results given in this work: Initially, the compensation level is regulated at 50%, where the system is stable, and then at $t = 0.5$ s, the compensation level is changed to 55%, where the system is unstable without SSRDC, due to the SSR mode. The SSRDC gain K_{SSR} in the simulation is obtained using root-locus diagrams, as mentioned in figure 4.2 and 4.4. The design process is verified from the Time-domain simulation in PSCAD/EMTDC.

V. CONCLUSION

From the above study and results, it can be concluded that the method of SSRDC design using rotor sped (ω_r) and line real power (P_L) as input control signal (ICS) when used to stabilize the SSR mode, causes unstable supSR or electromechanical mode (or even both together) regardless of the insertion point chosen for the SSRDC execution and may require complex compensation design in future investigation and research. Neither of RSC controllers can be used to execute the SSRDC, notwithstanding any ICS. SSRDC can be executed at all points of the GSC controllers when capacitor voltage V_C is used as ICS. Deploying capacitor voltage V_C as ICS in GSC, SSR can be damped successfully in furtherance with long distance power transfer capability.

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