Grid Side Converter Modeling In PMSG for System Level Studies In Average Value Model

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Abstract: This research proposes average value model (AVM) for PMSG grid side converter. Numerical tests are performed in AVM and in accordance with that PMSG detailed model were developed in PSCAD, and transient studies were done for system dynamics. PMSG based wind farms are influenced by sub-synchronous oscillations, i.e. to design accurate and efficient wind farms generators stability studies to be done. Average value model based modeling of converters were done in this research to study the proposed modification efficiency and results were analysied in simulation. Wind farms of different ratings and design are being designed and developed across the globe, research were going on for the better development of new generation model.

Keywords: Permanent Magnet Synchronous Generator (PMSG), Average vale model (AVM), Crowbar, sub-synchronous oscillation (SSO), Voltage Source Converter (VSC), Machine Side Converter (MSC), Generator Side Converter (GSC)

1. Introduction

In present era integration of distributed generation resources with main grid have introduced new stability problems. Similarly with the introduction of wind farms sub-synchronous oscillations (SSO), were studied widely due to its prolonged effect in system stability [1, 2]. It is found that both DFIG and PMSG based wind farms are influenced by SSO, this is pain point for designers to design and develop wind farms based on PMSG with improved stability. In PMSG integrated wind farms having weak AC link are prone to SSO [3,4] influence but from the point of stability this should be considered in designing.

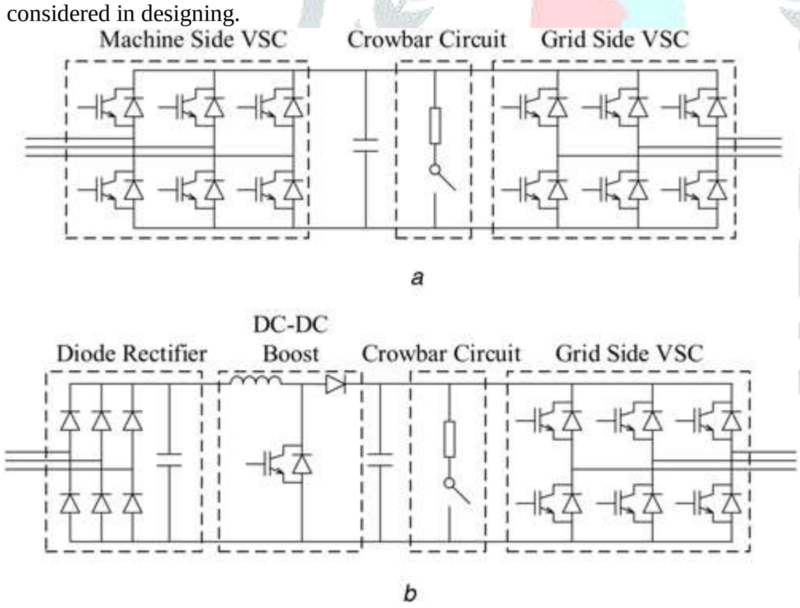


Fig. 1 Topologies of PMSG converter a) Type I converter b) Type II converter

Traditional modeling of components were done using system blocks switching and control block parameters, but when switching time increases their simulation output become unrealistic mostly. When large wind farm are modeled and its integration to power grid is done via this approach down time of simulation output increases which is not feasible and tolerable. If the system is modeled in Electromagnetic transient programme (EMTP), simulation time reduces and error due to switching transient between the channel transition were also eliminated, this is used to simulate the needed transition without signal generation errors. Here reduced PMSG model [5, 6] having specifically designed converter and crowbar is adopted to study SSO and low-voltage ride through (LVRT) analysis [7]. In simulation delimitations are always there but for modeling and programming system led to analysis the actual problems and enabling resilience to the system.

When system transient is studied, fault inside the generator and within converter will not affect system modeling responses, so this conditions can be ignored while system analysis. In average modelling technique control system and converter essential parameters characteristic is computed with consideration of dynamic response to PMSG. AVM is used for converter modeling [10], for DC-DC converter [9] modeling average circuit is effective.

The crowbar circuit used in system for PMSG converter circuit as simplified approach for EMTP computation have not been used before in any literature. In EMTP programming fixed time steps were used instead of iterations which are point to consider as a cause of error. Traditionally simulation is based on iteration and variable step integration as modeling done for state space analysis of GSC of PMSG wind-farms, whereas EMTP have fixed step computation.

2 Wind farm average value model for generator

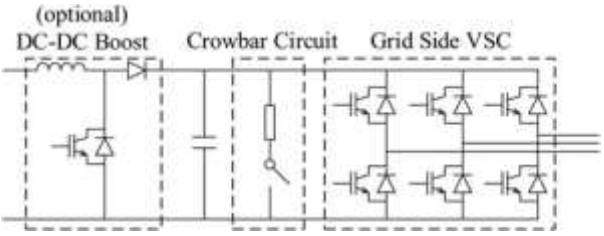


Fig. 2 System-level studies generalized model

2.1 Generalized model of Generator Side Converter (GSC)

PMSG wind generator is divided into three segment synchronous generator with permanent magnet, GSC and MSC. Topologies of converter configuration were shown in Fig.1 a & b; former topology consist of two VSC connected converter for both end via DC capacitor and crowbar circuit [4, 9], later topology consist of three phase bridge diode, DC-DC boost converter connected via crowbar circuit to inverter circuit as MSC and GSC. As both converter were isolated via large DC capacitor this will eliminate propagation of transients from each side. Simplified modeling of PMSG wind generators were done and in this SSO, LVRT and fault analysis will be performed instead of implementing in detailed circuit. In Fig. 2, type –II topology is detailed with different stages of converter connections.

2.2 Average value model for the DC–DC boost converter

Type-II topology DC-DC boost converter is modeled via average vale modeling [9], as shown in Fig. 3b, where power electronics switches were modeled as controlled sources. DC-DC converter switch inductor cell [8, 9] model is deducted from the system level studies of generalized model.

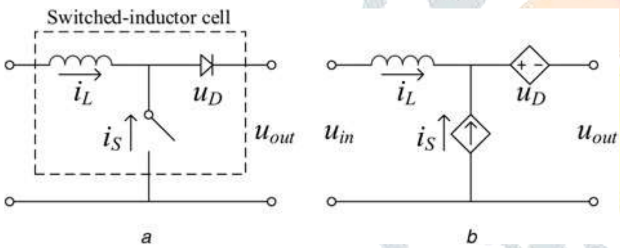


Fig. 3 DC–DC boost converter a) DC–DC boost converter b) AVM for DC–DC boost converter

The values for the controlled sources are dependent on the controlled duty ratio as

$$\bar{i}_S = -\frac{d_1}{d_1 + d_2}\bar{i}_L$$
$$\bar{u}_D = (1 - d_1 - d_2)(\bar{u}_{in} - \bar{u}_{out}) - d_1\bar{u}_{out} \quad (1)$$
$$d_2 = \min\left\{\frac{2L\bar{i}_L f_{sw}}{d_1 \bar{u}_{in}} - d_1, 1 - d_1\right\}$$

Where, i_S – Controlled Current, u_D – Controlled Voltage, d_1 – Duty Ratio of boost converter

As system is to be programmed in-EMTP but it is not directly modeled in PSCAD as controlled source involve algebraic loop, where the computation for i_S and u_D require the value of inductor current i_L, input, and the output voltage at the same instant.

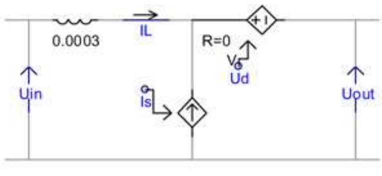
$$\tilde{f}(t) = \frac{5}{4}f(t - \Delta t) + \frac{1}{2}f(t - 2\Delta t) - \frac{3}{4}f(t - 3\Delta t) \quad (2)$$

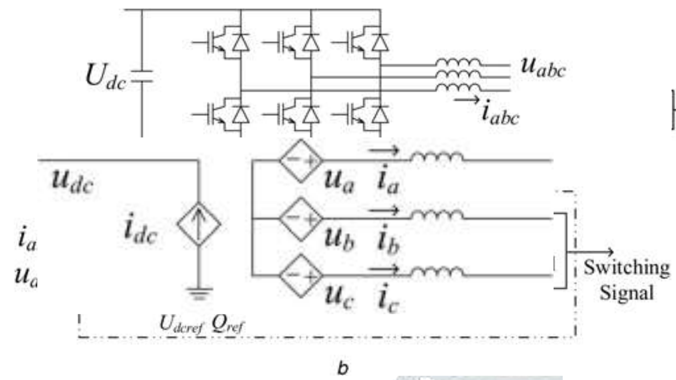
The average value model for DC–DC boost converter built in PSCAD/EMTDC is provided in Fig. 4. The calculation for i_S and u_D are modelled using continuous system model function blocks in PSCAD.

2.3 Average value model of the DC–AC VSI

The grid-side converter in a PMSG wind generator can be modelled as a three-phase PWM VSI as represented in Fig. 5. As ABC to DQ conversion for system control followed by UQ control generates the duty ratio reference signals d_{abc_ref} for PWM control. The duty ratio reference signals are then compared with the carrier wave to generate the final switching signals.

$$u_{abc} = \frac{1}{2}u_{dc}\min\left\{\frac{d_{abcref}}{u_{tri}}, 1\right\}$$
$$i_{dc} = \frac{u_{abc}^{T} i_{abc}}{u_{dc}} \quad (3)$$





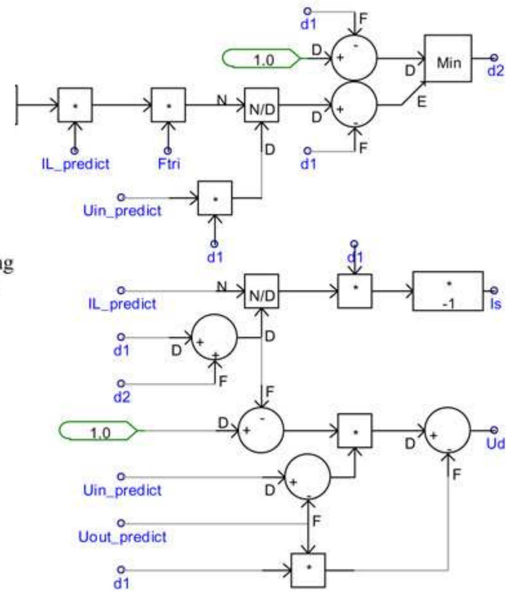


Fig. 5 Three-phase PWM VSI a Three-phase PWM VSI b Control system of the VSI

Fig. 6 AVM of the VSI

Fig. 4 AVM of the DC–DC boost converter in PSCAD a) Main circuit b) Controlled sources calculation

The average value model for VSI cannot be easily implemented in EMTP, as algebraic loops are involved in (3), for this equivalent circuit is modeled with the detailed consideration that required parameters and characteristic will be part of equivalent system. However, the onetime delay and predictor can still be applied in the AVM for VSI, where the DC side voltage in (3) is predicted using (2).

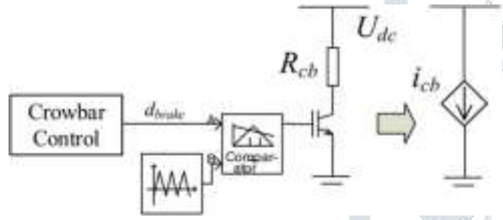


Fig. 7 Crowbar circuit and its average value equivalent

2.4 Average value-based crowbar circuit

The crowbar circuit in PMSG is a protection circuit for the converter, in order to suffer the severe external fault. A typical topology for the crowbar circuit [7] can be modelled using a resistance and a controlled switch, as in Fig. 7. In normal states, the switch is open (d_{brake} =0), so that the crowbar is blocked. During the Fig. 4 AVM of the DC–DC boost converter in PSCAD faults, the switch may operate in PWM mode, in order to discharge a Main circuit the active power through the crowbar resistance R_{cb}. b Controlled sources calculation

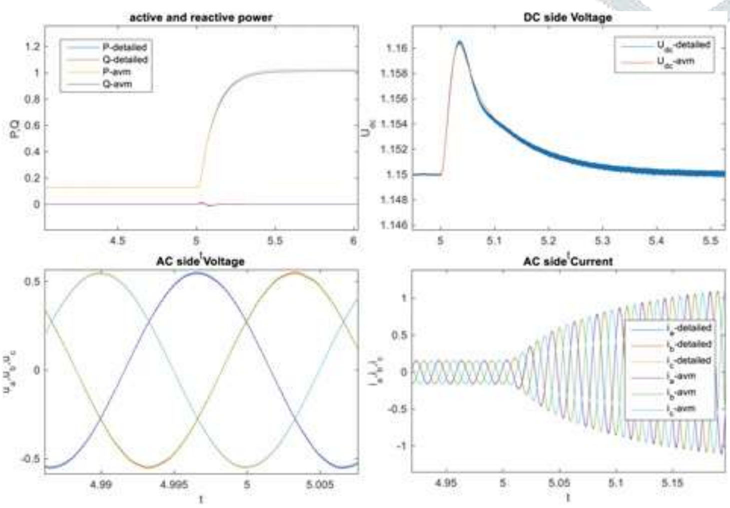


Fig. 8 Results of slow transients studies

When modelling the crowbar circuit by its average value, only a controlled current source is used, which is calculated as

$$i_{ch} = \frac{d^2}{R_{ch}} u_{dc+} \quad (4)$$

Obviously, the calculation for controlled current source also involves an algebraic loop. As a result, one time-step delay and the prediction formula (2) can be applied here as well.
Finally, the entire converter circuit is modelled in average value form, as shown in Fig. 8. It can be seen that there are no PWM blocks and switches used in this AVM. Then, during related EMTP simulations, large integration time steps can be adopted, which can significantly accelerate simulation-based stability studies of large-scale wind farms.

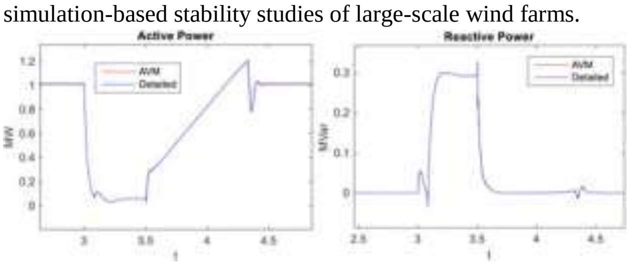
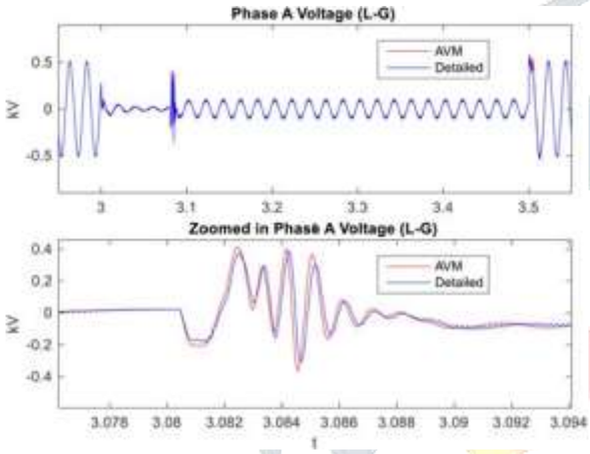


Fig. 9 Results of measured power during fault studies



3. Case studies

In this section, a Type-II PMSG wind generator test case is provided to validate the proposed AVM model. The PMSG wind generator is connected to an infinite bus through a three phase transformer. Both the detailed model and the average value model are built and compared in PSCAD/EMTDC. The test cases are simulated in different scenarios, including slow system-level transients, AC-side three phase short-circuits fault, and frequency sweeping analysis.

The detailed case simulates using an integration time-step of 5 μs, while the proposed model uses 100 μs for all the tests.

3.1 Fault studies with LVRT process

In this test, a three-phase grounded fault occurs at 3 s and clears at 3.5 s. The crowbar protection and LVRT control are enabled during the simulation. The measured power and voltages of phase A are provided in Figs.9 and 10.

As seen from Figs.9 and 10, the AVM provides acceptable fault results compared with the detailed model even using a large integration step. The active and reactive power matches well with the curves of the detailed model, while the largest relative error for AC side voltage remains <10% during fast transients. The above test shows that the proposed model is also accurate enough for fast system-level transient analysis such as severe external fault simulation.

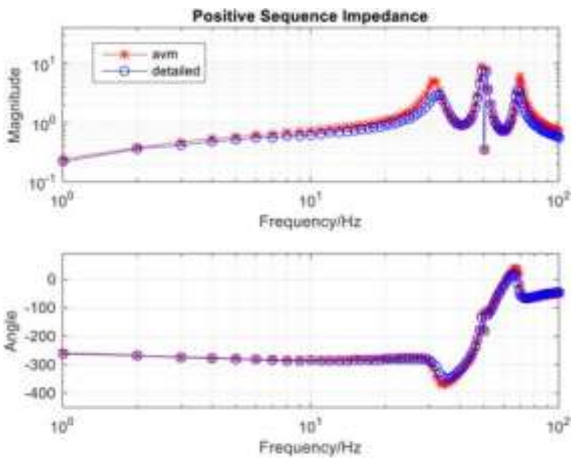


Fig. 10 Results of measured voltage during fault studies

Fig. 11 Results of positive sequence impedance

Table 1 Time-costs comparison and speedups. Duration of simulation is 5 s for all the cases

Time step, μs	Detailed model	AVM, s	Speedups
5	2943s	1201	2.2
10	—	654	4.2
50	—	142	18.5
100	—	81	33.6

3.2 Frequency-sweeping analysis

As the frequency-dependent impedance is important for the SSO-related studies; thus, frequency sweeping tests are also performed to validate the proposed model.

In this test, the positive sequence harmonic impedance of the PMSG is measured around the operating point (P=1000 kW, Q=0 kVar) by injecting positive currents of different frequencies (1–100 Hz) at the terminal of the PMSG. It can be seen from Fig.10 that the proposed average value model presents good accuracy compared with the detailed model in the frequency-sweeping test.

4. Conclusion

In this research paper, wind farm based on PMSG is modeled by average value modeling for system-level studies is proposed. The model contains three parts, i.e. an optional DC–DC boost converter, a crowbar circuit, and a DC–AC VSI. The proposed model in different scenarios including slow and fast system-level transients accuracy simulation results were also analysied. By enabling large integration steps, the proposed model also shows great numerical efficiency than the detailed model. The good accuracy and high efficiency make the proposed model available and more suitable for large-scale wind farm simulations.

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