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# Fuzzy based STATCOM for improving the dynamic stability of parallel connected PMSG Offshore wind Turbines

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***Abstract***— ***This paper proposes a dynamic stability improvement of four parallel connected Offshore wind turbines with a shunt connected static synchronous compensator (STATCOM). Permanent magnet synchronous generator (PMSG) is used for power generation in wind farms while the onshore power system is simulated by a synchronous generator (SG) fed to an infinite bus through two parallel transmission lines. A damping controller of the proposed STATCOM is designed by using FUZZY logic controller, Which is improves the performance point of STATCOM. It can be concluded from the simulation results that the proposed STATCOM joined with the designed damping controller can effectively improve the stability of the studied SG-based onshore power system under various disturbance conditions.***

***Index Terms— Dynamic stability, permanent-magnet synchronous generator (PMSG), pole-assignment approach, static synchronous compensator, wind turbine generator (WTG).***

## I. INTRODUCTION

Renewable energy is one of the hottest themes in the entire world today due to the fast and huge consumption of fossil fuels. Some academic researchers have devoted to high-capacity offshore wind turbine generators (WTGs) connected to onshore substations through undersea cables .Currently, wind doubly-fed induction generators (DFIGs) and wind permanent-magnet synchronous generators (PMSGs) have been widely used in high-capacity offshore wind farms (OWFs) [1]. From the historical point of view, a direct-coupled, modular PMSG for variable-speed wind turbines was proposed and multiple single-phase outputs were separately rectified to obtain a smooth dc link voltage.

The dynamic model based on small-signal stability of a wind turbine (WT) using a direct-drive PMSG with its power converters and controllers was proposed [2].

Regarding the applications of STATCOM to power-system stability improvement, the stability enhancement of power systems using STATCOMs and the damping controller design of STATCOMs were presented in [9]. A variable-blade pitch of a WTG and design of an output feedback linear quadratic controller for a STATCOM to perform mechanical power control and voltage control under different operating conditions were studied in [10]. Controller design and system modeling for quick load voltage regulation and suppression of voltage flicker using a STATCOM.

A novel D-STATCOM control algorithm for enabling separate control of positive- and negative-sequence currents was proposed in [12]. Dynamic characteristics of a power system with a STATCOM and a static synchronous series compensator (SSSC) through digital simulations were compared in [13]. The application of a STATCOM to damp torsional oscillations of a series-capacitor compensated ac system. The characteristics of using PSS, static VAR compensator (SVC), and STATCOM for damping undesirable inter area oscillations of a power system were compared in [15]. These days, with the fast advance of high-capacity power-electronics technology, large commercial wind turbine generators can be practically employed to contribute high generated power to power systems, where wind PMSGs with full back-to-back converters have proven to be good choices for high-power WTGs. Basically, the grid-side converter of the PMSG-based WTG can be operated as a STATCOM. Many manufacturers also provide this option even for the case when the WTG is not running. But in a real PMSG-based OWF, it has several PMSG-based WTGs operating together, and it is difficult to control reactive power of all WTGs at the same time to supply adequate reactive power to the system. Hence, to guarantee good power quality (PQ) of the system, an additional VAR compensator is required. In this paper, a STATCOM is proposed as a VAR compensator.

## II.CONFIGURATION OF THE STUDIED SYSTEM

Fig.1 shows the configuration of the studied system. The right-hand side of Fig.1 represents the synchronous generator (SG)-based one-machine infinite-bus (OMIB) system. Two parallel-operated 615-MVA SGs are connected to an infinite bus (or a power grid) through two parallel transmission lines (TL1 and TL2) and a 15/161-kV step-up transformer. Four parallel-operated PMSG-based WTGs and a 5-MVAR STATCOM are connected to the common offshore ac bus that is fed to the point of common coupling (PCC) of the OMIB system through a step-up transformer of 23/161 kV and a cable (undersea and underground cables). Each 5-MW WTG is represented by a PMSG with an ac/dc converter, a dc link, a dc/ac inverter, and a step-up transformer of 3.3/23 kV. While the shaft of the wind PMSG is directly driven by a variable-speed WT. the four PMSG-based WTGs, the STATCOM, and a local load are connected to a common ac bus through connection lines and transformers.

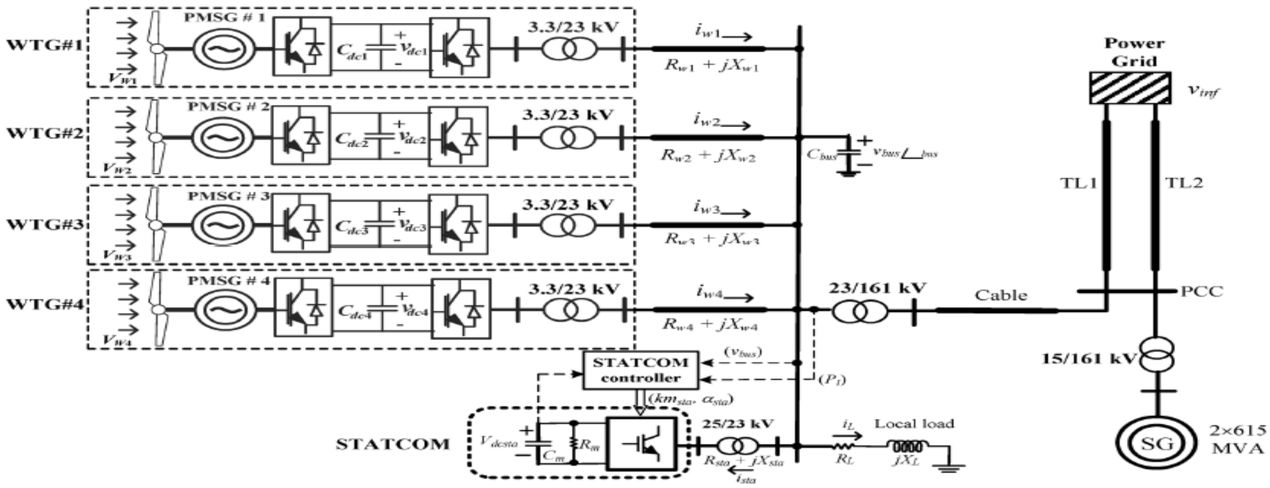



Fig. 1 Configuration of the studied SG-based containing four parallel-operated PMSG-based WTGs with STATCOM

## III.WIND TURBINE MODEL

The blade pitch angle (degrees) are the constant coefficients. The wind speed is modeled as the algebraic sum of a base wind speed, a gust wind speed, a ramp wind, and a noise wind speed. The cut-in, rated, and cut-out wind speeds of the studied WT are 4, 14, and 25 m/s, respectively. When wind speed is lower than 14 m/s, When 14 m/s, the pitch-angle control system activates and increases accordingly. In fig.2 Each WT is directly coupled to the rotor shaft of a wind PMSG.

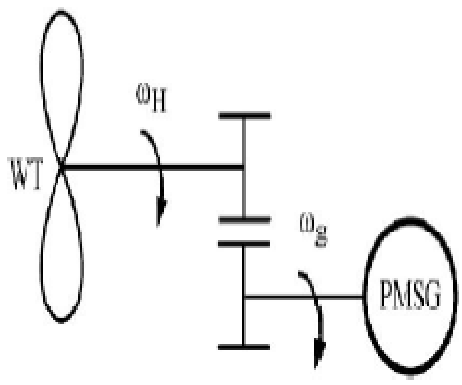



Fig2. Each WT coupled to the rotor shaft of a wind PMSG

## IV.PMSG AND POWER CONVERTER

The power converter of each wind PMSG consists of a voltage source converter (VSC) and a voltage-source inverter (VSI) as shown in Fig. 3. The VSC or the VSI consists of six insulated gate bipolar Properly decoupled by the dc- link capacitor . The common dc link with a large capacitor is connected between the VSC and the VSI. The operation of the VSC and the VSC is properly decoupled by the dc-link capacitor and, hence, the VSC and the VSI have independent controllers.

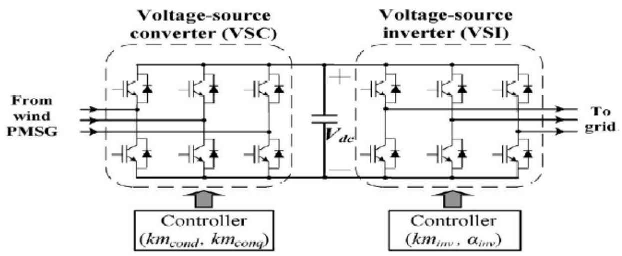



Fig 3 . Model of power converters of the studied wind PMSG

## V.STATCOM MODEL

In order to temporarily avoid the high level of reactive compensation during recovery. In addition to the normal STATCOM control, allows for torque transient alleviation during the recovery process after a grid fault [4]. This is possible to achieve by reducing the voltage reference of the STATCOM control system and, by that, the reactive compensation when stability is ensured after fault clearing but before the grid voltage and the speed of the generator have returned to the pre-fault values [6]. In this way, the STATCOM can improve the torque capability of the PMSG when this is needed keep the system stable, and once stability is ensured, it can reduce the maximum torque during recovery. The strain on the drive train can thereby be reduced. This is particularly relevant where wind turbines cannot just disconnect from the grid to protect the installation from risk of mechanical damage that might be caused by the cumulative stress of repeated peak torque transients[5] This paper focuses on the recovery process after fault clearing and reactive power compensation .The other main issue related to this concept is that, since the decelerating torque of the generator is limited, the recovery process of the system will be longer than for the case of normal control of the STATCOM with a fixed voltage reference value[8].

## VI. CLASSIFICATION BASED ON FUZZY LOGIC METHOD

Now we have to extend the above paper by using the fuzzy rules and in the below I have detail wrote the rules and we have to absorb the corresponding current output waveforms and waveform for the THD calculation

**Fuzzy rules**:

| rule.no | Error(e) | Change in error(Δe) | Output |
|---|---|---|---|
| 1 | NB | NB | NB |
| 2 | NB | NM | NB |
| 3 | NB | NS | NB |
| 4 | NB | ZE | NB |
| 5 | NB | PS | NM |
| 6 | NB | PM | NS |
| 7 | NB | PB | ZE |
| 8 | NM | NB | NB |
| 9 | NM | NM | NB |
| 10 | NM | NS | NB |
| 11 | NM | ZE | NM |
| 12 | NM | PS | NS |
| 13 | NM | PM | ZE |
| 14 | NM | PB | PS |
| 15 | NS | NB | NB |
| 16 | NS | NM | NM |
| 17 | NS | NS | NS |
| 18 | NS | ZE | NS |
| 19 | NS | PS | ZE |
| 20 | NS | PM | PS |
| 21 | NS | PB | PM |
| 22 | ZE | NB | NB |
| 23 | ZE | NM | NM |
| 24 | ZE | NS | NS |
| 25 | ZE | ZE | ZE |
| 26 | ZE | PS | PS |

| | | | |
|---|---|---|---|
| 27 | ZE | PM | PM |
| 28 | ZE | PB | PB |
| 29 | PS | NB | NM |
| 30 | PS | NM | NS |
| 31 | PS | NS | ZE |
| 32 | PS | ZE | PS |
| 33 | PS | PS | PS |
| 34 | PS | PB | PB |
| 35 | PS | PM | PM |
| 36 | PM | NB | NS |
| 37 | PM | NM | ZE |
| 38 | PM | NS | PS |
| 39 | PM | ZE | PM |
| 40 | PM | PS | PM |
| 41 | PM | PM | PB |
| 42 | PM | PB | PB |
| 43 | PB | NB | ZE |
| 44 | PB | NM | PS |
| 45 | PB | NS | PM |
| 46 | PB | ZE | PB |
| 47 | PB | PS | PB |
| 48 | PB | PM | PB |
| 49 | PB | PB | PB |

## VII. SIMULATION AND RESULTS

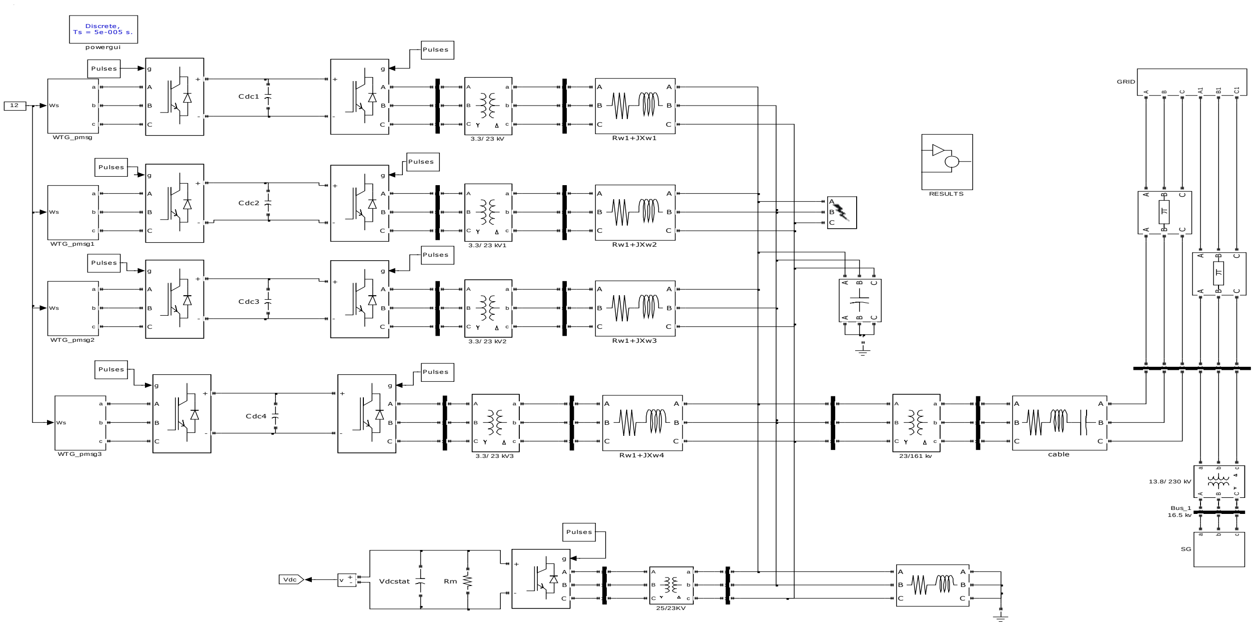
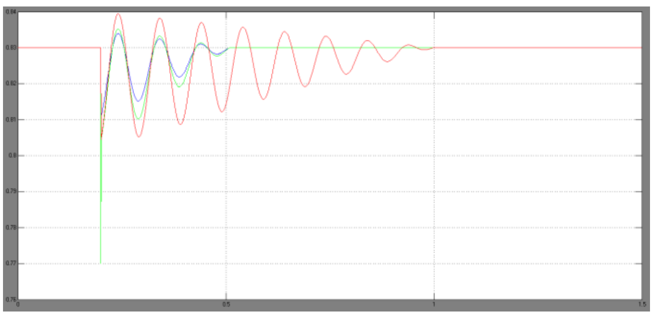
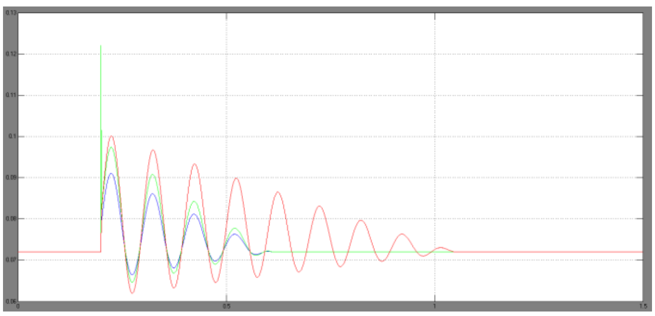


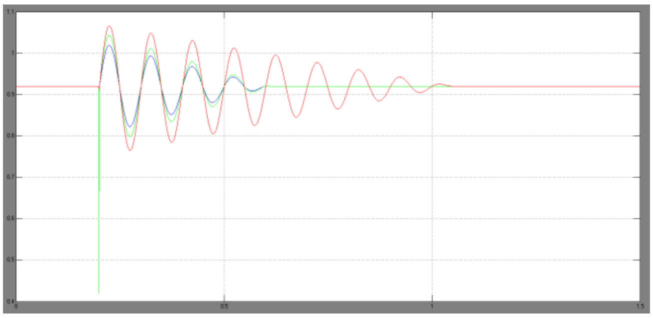

**Fig.4 Simulink model for proposed system**



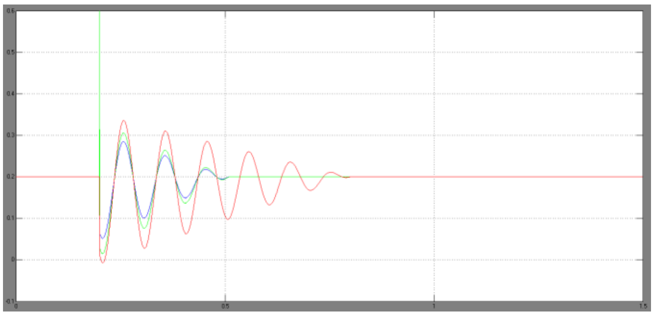
**(a)**



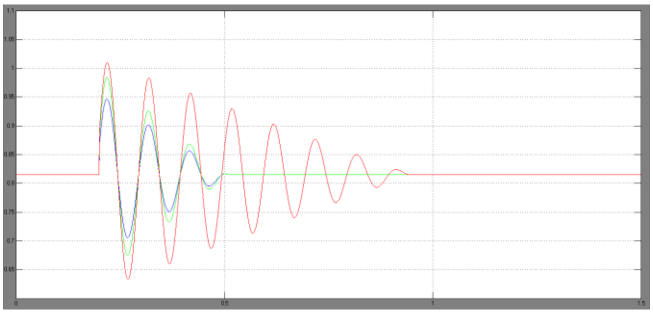
**(b)**



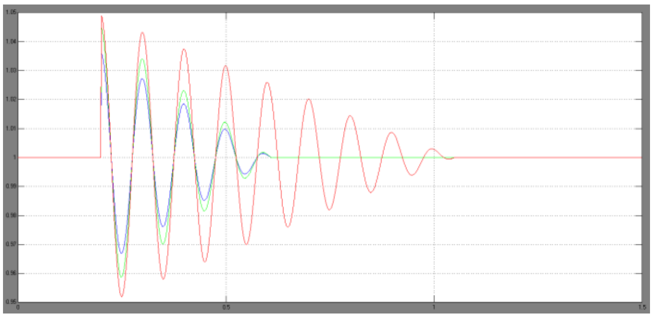
**(c)**



**(d)**



**(e)**



**(f)**

**Fig.5 Simulation results of proposed system (a)P1 (b)Q1 (c)Psystem (d)Qsystem (e)Psg (f)Qsg**

## VII. CONCLUSION

This paper has presented the stability improvement of four parallel-operated PMSG-based WTGs connected to an SG based OMIB system. The STATCOM is proposed and is connected to the common ac bus of the four WTGs to supply adequate reactive power and offer proper damping. A FUZZY damping controller has been designed for the STATCOM. Simulations of the studied system subject to a three-phase short-circuit fault at the power grid have been systematically

Performed to demonstrate the effectiveness of the proposed STATCOM joined with the designed FUZZY damping controller on suppressing inherent SG oscillations and improving system stability under different operating conditions better than PID damping controllers. It can be concluded from the simulation Fig.5 results that the proposed.

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