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A Control Scheme Using A STATCOM For A Grid Connected OWF And MCF To Improve The Dynamic Stability of The System

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*Abstract—***This paper presents a Novel control scheme is based on the STATCOM for the grid connected integrated system which has 80-MW offshore wind farm (OWF) and 40-MW marine current farm (MCF) to achieve the both voltage control and damping enhancement. The PID damping controller is designed for the STATCOM to contribute effective damping characteristics to the studied system under different operating conditions such as noise wind speed disturbances and marine current speed disturbances. A frequency-domain approach based on a linearized system model using Eigen value techniques and a time-domain scheme based on a nonlinear system model subject to various disturbances are employed to simulate the effectiveness of the proposed control scheme. It can be concluded from the simulated results that the proposed STATCOM joined with the designed PID damping controller is very effective to stabilize the studied system under disturbance conditions. The voltage fluctuations of the AC bus subject to the active-power variations of the studied system can also be effectively controlled by the proposed control scheme. The system performance is also improved.**

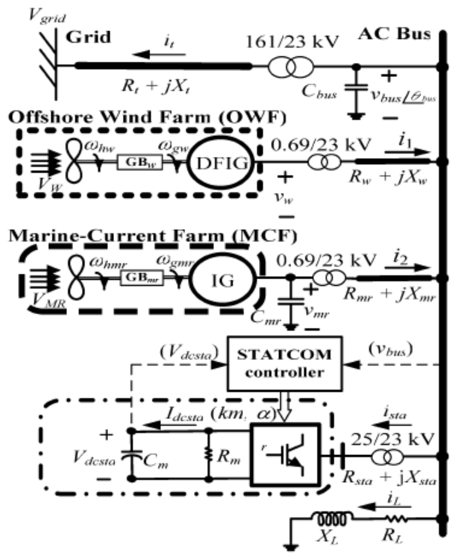
Index Terms– **Offshore Wind Farm; Marine Current Farm; Static Synchronous Compensator; Dynamic Stability;**

I. INTRODUCTION

Now-a-days utilization of the renewable energy resources are outstandingly increased day by day because of the free availability, Natural resources have tremendous amount of the energy, We are converting this energy into electrical energy with free of pollution and reduces greenhouse effect gasses, Now we are using wind energy and ocean energy, Oceans cover the more than 70% of the earth, Ocean energy partially contains the thermal energy and the kinetic energy (waves and currents), The kinetic energy in the marine and tidal currents can be converted into electrical energy by using conventional turbine technology, Obviously the wind speed is more at the sea shores than on land, The generator is driven by the Marine Current Turbine (MCT) is combined with the offshore generator which is driven by Wind Turbine (WT) will become a novel scheme to produce the energy for future, This is a hybrid power generation system containing both Offshore Wind Farm (OWF) and Marine Current Farm (MCF), This system can be extensively developed at the specific locations of the world in the future, Offshore Wind Farm (OWF) with Wind Turbine (WT), gear box and Doubly Fed Induction Generator (DFIG) connected to the grid, at AC bus through the offshore step up transformer and undersea cables, Similarly Marine Current Farm (MCF) with marine current turbine (MCT), gear box and Squirrel Cage Induction Generator (SCIG) connected directly to the power grid through an offshore step up transformer and undersea cables, Both WT and MCT have very similar characteristics but SCIG based MCF requires the reactive power for magnetization and generated active power is also varied due to marine current fluctuations and absorbed reactive power, terminal voltage while a DFIG based OWF has bi-directional power converters (RSC, GSC) to control the output power factor near to unity, A control scheme of the hybrid power generated system, based on a Static Synchronous Compensator (STATCOM) to achieve both voltage control and damping enhancement with PID damping controller, A damping controller of the STATCOM is designed by using modal control theory to contribute the effective damping characteristics to the studied system under different operating conditions, A frequency-domain approach is done by the Eigen value techniques based on a Linearized system model and time-domain approach based on the nonlinear system model under various disturbances, These both are employed to simulate effectiveness of the proposed control scheme, The proposed STATCOM joined with the designed PID damping controller is very effective to stabilized system under disturbance conditions, The voltage fluctuations of the AC bus subject to the active power variations of the studied system can also be effectively controlled by the proposed control scheme, Stability of the power system is improved by using the damping controller of the STATCOM, A variable blade pitches of a wind energy conversion system to perform both voltage control and mechanical power control under grid connection, The STATCOM is demonstrated for system modeling and controller design for fast load voltage regulation mitigation for voltage flicker,

II. SYSTEM MODELS

Fig, 1 shows the configuration of the studied integrated DFIG-based OWF and SCIG-based MCF with the proposed STATCOM, The OWF, the MCF, the STATCOM and a local load are connected to an AC bus that is fed to the onshore power grid through an offshore step-up transformer and undersea cables,



Fig, 1 Configuration of the integrated OWF and MCF with STATCOM

A. Wind Turbine

The mechanical power (in W) produced by a WT can be expressed by

$P_{mw} = ½ \rho_{w,} A_{rw}, V^3_W , C_{pw} (\lambda_w, \beta_w)$-(1)

Where P_{mw}- mechanical power produced by the WT (w), ρ_w –air density (kg/m^3), A_{rw}-blade impact area (m^3), V_W-wind speed (m^3), C_{PW}-power co-efficient of the WT, The power coefficients C_{PW} gives the fraction of the kinetic energy that is converted into the mechanical energy by the wind turbine, It is a function of the tip speed ratio λ and depends on the blade pitch angle β for pitch controlled turbines,

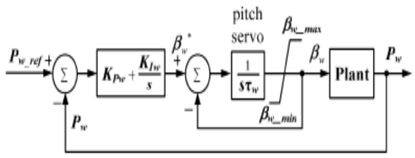


Fig-2 Block diagram of the pitch-angle control system of the WT

When V_W is lower than the rated wind speed of the wind turbine ($V_{W\ RATED}$), the pitch angle β_w =0, When V_W>V_{WRATED} the pitch angle control system of the WT is activated and pitch angle of the WT (β_w) increases to limit the active power of the WT, The cut-in, rated, and cut-out wind speeds of the studied WT are 4, 15, and 24 m/s, respectively,

B. Marine Current Turbine

The mechanical power (in W) generated by the MCT is given by the equation

$P_{mmr} = ½ \rho_{mr} , A_{rmr\,,} V^3_{MR} ,C_{pmr}(\lambda_{mr},\beta_{mr})$

Where P_{MR}-mechanical power developed by the MCT (w), ρ_{mr} –sea water density (kg/m3) {which is 1025 kg/m3}, A_{MR} –blade impact area (m^2),V_{MR}– marine velocity (m/s), C_{PMR}-power co-efficient of MCT, The cut-in, rated, and cut-out speeds of the MCT are 1, 2,5, and 4 m/s respectively, When $_{VMR}$ is higher than the rated speed, pitch angle control system of the MCT activates to limit the output power of the MCT at rated values,

C. Doubly Fed Induction Generator

The stator windings of the wind DFIG are directly connected to the low-voltage side of the 0,69/23-kV step-up transformer while the rotor windings of the DFIG are connected to the same 0,69-kV side through a rotor-side converter (RSC), a DC link, a grid-side converter (GSC), a step-up transformer, and a connection line, By using these converters rotor frequency can easily differ from the grid frequency,

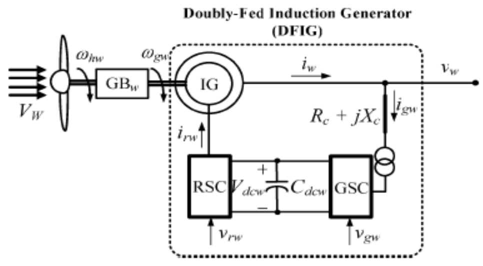


Fig-3 One line diagram of the DFIG

For normal operation of a wind DFIG, the input AC-side voltages of the RSC and the GSC can be effectively controlled to achieve the aims of simultaneous output active-power and reactive-power control,

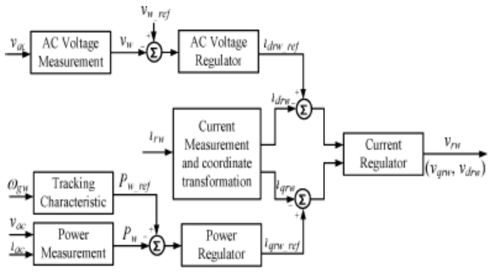


Fig-4 Control block diagrams for the RSC of the DFIG

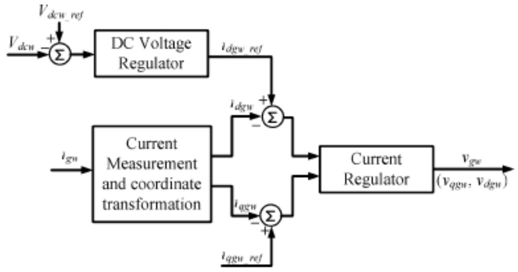


Fig-5 Control block diagram for the GSC of the DFIG

The operation of the RSC requires i_{qrw} and i_{drw} to follow the varying reference points that are determined by maintaining the output active power and the stator winding voltage at the setting values respectively, The per-unit q-axis and d-axis currents of the GSC, i_{qgw} and i_{dgw} have to track the reference points that are determined by maintaining the DC link voltage V_{dcw} at the setting value and keeping the output of the GSC at unity power factor respectively,

D. STATCOM

A three phase six pulse STATCOM is used, It has IGBTs and anti parallel diodes,

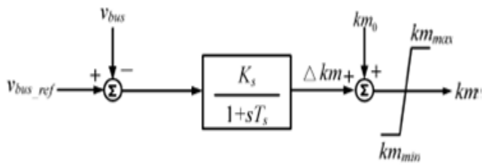


Fig-6 Control block diagram of the STATCOM

The per-unit q-axis and d-axis output voltages of the STATCOM are

$V_{qsta} = V_{dcsta}, km, \cos(\theta_{bus}+\alpha)$

$V_{dsta} = V_{dcsta}, km, \sin(\theta_{bus}+\alpha)$

Where v_{qsta} – per unit q-axis voltage at the output terminal of STATCOM, v_{dsta} – per unit d-axis voltage at the output terminal of STATCOM, θ_{bus} - phase angle of the AC bus voltage V_{dcsta} – per unit DC voltage of the Dc capacitor $C_{m,}$ Km – modulation index, α- phase angle of the STATCOM.

E. STATCOM+PID

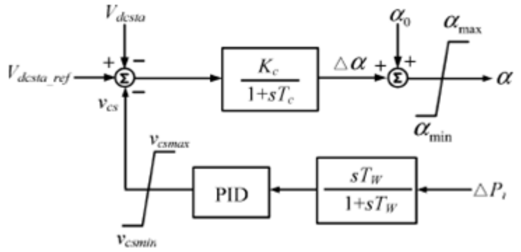


Fig-7 control block daigram of STATCOM with PID

The PID damping controller is designed for a STATCOM by using a Modal Control Theory to improve the dynamic stability of the studied system, The operating point to design the PID damping controller for STATCOM is (V_W, V_{MR}) = (12m/s, 2,5m/s)

III. DESIGN OF THE PID CONTROLLER

The nonlinear system models developed in section-11 are first linearized around a nominal opertaing point to obtaine a set of linearized system equations in matrix form,

$pX = AX+BU+VW$ (1)

$Y = CX+DU$ (2)

Where X- State vector, Y –output vector, U- External input vector, W-Disturbance vector, A, B, C, and D – Constant matrices, To design the PID damping controller for the proposed STATCOM, the disturbance input vector W and external input vector U can be properly neglected i,e, D = V = 0,

The state vector X has the five sub state vectors as

$X = [X_{DFIG,} X_{SCIG}, X_{MECH}, X_{ELEC}, X_{STA}]^T$

Where X_{DFIG} – State vector of the wind DFIG, X_{SCIG} – State vector of the marine-current SCIG, X_{MECH} – State vector of the mechanical system of both WT and MCT X_{STA} – State vector of the STATCOM, X_{ELEC} – State vector of the electrical system including the AC bus, three transmission lines and local load, Because the V_W seldom reaches the rated wind speed of 15 m/s and V_{MR} seldom operated above the rated marine-current speed of 2,5 m/s , V_W of 12 m/s and V_{MR} of 2,5 m/s are properly selected as the operating points for designing the PID controller of the STATCOM, Output vector Y = ΔP_T and input vector U = $V_{CS,}$ The transfer function H(s) of the proposed PID damping controller in s domain is given by

$H(s) = U(s)/Y(s) = v_{cs}(s)/\Delta P_t(s)$

$= \frac{sTW}{1+sTw}(K_p+K_I/s+sK_D)$ (3)

Where T_W is the time constant of the wash-out term must be positive, while K_P, K_I, and K_D are the proportional, integral and derivative gains of the damping controller respectively, The gains of the PID damping controller should be as small as possible, Taking Laplace transformation of (1)-(2), an algebraic equation of the closed loop system containing the PID controller can be obtained, The input signal can be expressed by the

$$U(s)=H(s)\Delta P_t(s)=H(s)Y(s)=H(s)CX(s) \quad (4)$$

Combining (3)-(4), we have

$$sX(s) = \{A+B\,[H(s)\,C]\}X(s) \quad (5)$$

The characteristic equation of the closed-loop system including the PID damping controller is given by

$$\text{Det}\,\{sI-[A+BH(s)\,C]\} = 0 \quad (6)$$

To solve this we will get Eigen values of the studied integrated system OWF and MCF with the proposed STATCOM joined with designed PID damping controller, All the system Eigen values are located on the left half of the complex plane under a fixed wind speed and a fixed marine current speed, which means selected operating conditions,

IV. NONLINEAR MODELS

The wind speed and marine current speeds are the time varying quantities, The damping characteristics contributed by the proposed STATCOM joined with the design PID damping controller to improve the damping stability of the studied system under a noise wind-speed disturbance and marine current-speed disturbances,

A. Noise Wind-Speed Disturbance

Fig-8(a)-(g) illustrate the studied system with and without the proposed STATCOM and designed PID damping controller under the noise wind-speed disturbance as shown in fig-(h),Simulation sequence is as below, When 0s< t < 0,5s , the OWF operates under a base wind speed of 12m/s and the MCF operates under a base marine-current speed of 2,5m/s, When 0,5s< t < 30s, the noise-wind speed (nearly V_W=13,5m/s) as shown below is added to the system but marine-current speed is still kept at 2,5m/s in fig (h),

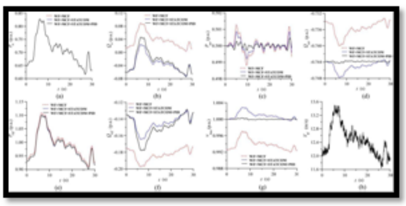


Fig-8 (a) P_w , (b) Q_w , (c) P_{mr}, (d) Q_{mr} , (e) P_{inf} , (f) Q_{inf} , (g) v_{bus} , (h)V_w

B. Marine current-speed disturbance

Marine currents are varied with time, When t<0s, the OWF operates under a base wind speed of V_W=12 m/s and MCF operates under a base marine-current speed of V_{MR}=2,5m/s,

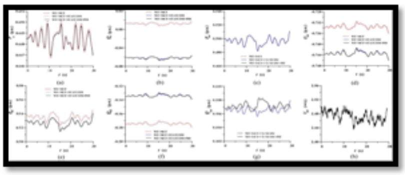


Fig-9 (a) P_w , (b) Q_w , (c) P_{mr}, (d) Q_{mr} , (e) P_{inf} , (f) Q_{inf}, (g) v_{bus}, (h) Vw

V. MATLAB SIMULATION RESULTS

MATLAB simulation diagram is as shown below,

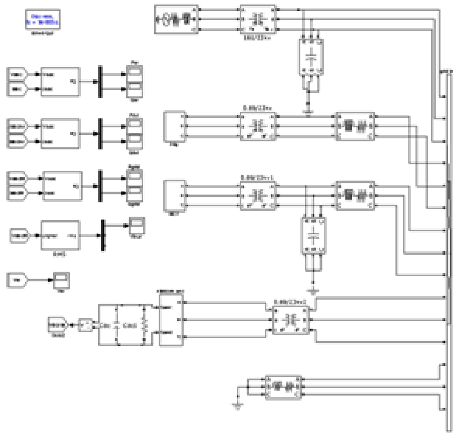


Fig-10 MATLAB simulation diagram

The Simulation results of the studied system with under disturbances,

a) Noise wind-speed disturbance

1) OWF and MCF

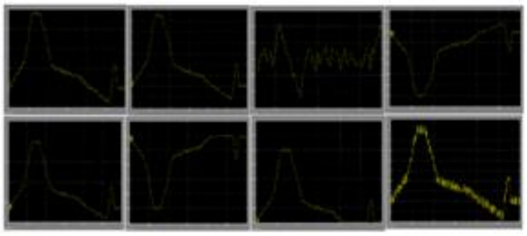


Fig-11 (a) P_w , (b) Q_w , (c) P_{mr}, (d) Q_{mr} , (e) P_{inf} , (f) Q_{inf}, (g) v_{bus}, (h) Vw

2) OWF and MCF with STATCOM

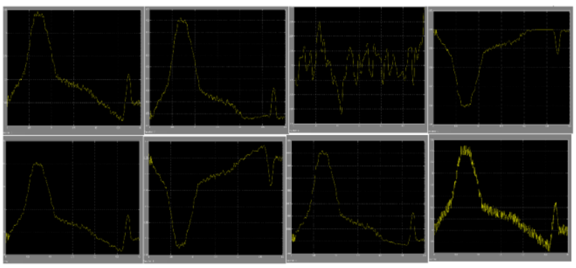


Fig-12 (a) P_w , (b) Q_w , (c) P_{mr}, (d) Q_{mr} , (e) P_{inf} , (f) Q_{inf}, (g) v_{bus}, (h) Vw

3) OWF and MCF with STATCOM+PID

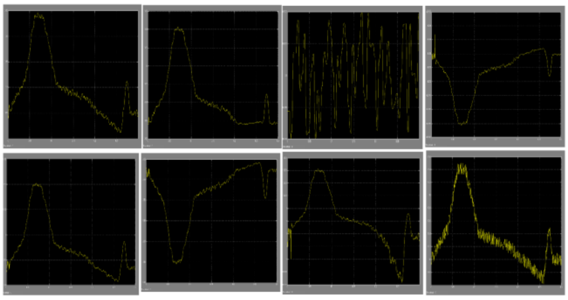


Fig-13 (a) P_w , (b) Q_w , (c) P_{mr}, (d) Q_{mr} , (e) P_{inf} , (f) Q_{inf}, (g) v_{bus}, (h) Vw

b) Marine current speed-disturbance

1. OWF and MCF

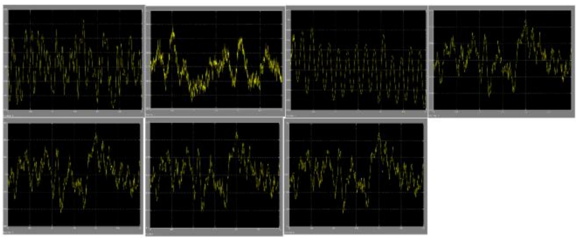


Fig-14 (a) P_w , (b) Q_w , (c) P_{mr}, (d) Q_{mr} , (e) P_{inf} , (f) Q_{inf}, (g) v_{bus}, (h) Vw

2. OWF and MCF with STATCOM

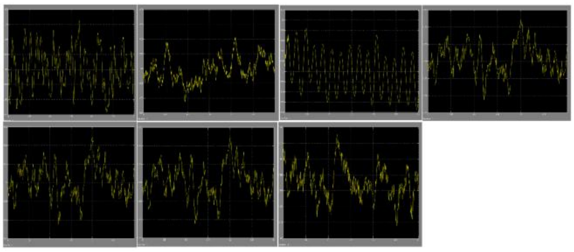


Fig-15 (a) P_w , (b) Q_w , (c) P_{mr}, (d) Q_{mr} , (e) P_{inf} , (f) Q_{inf}, (g) v_{bus}, (h) Vw

3. OWF and MCF with STATCOM+PID

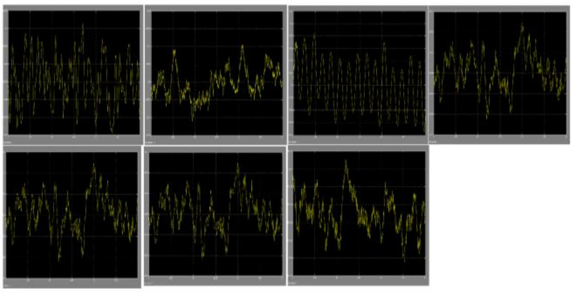


Fig-16 (a) P_w , (b) Q_w , (c) P_{mr}, (d) Q_{mr} , (e) P_{inf} , (f) Q_{inf}, (g) v_{bus}, (h) Vw

We are measuring the Percentage of Total Harmonic Distortion (THD) to the studied system and the simulation diagrams are as shown below, Fig-17 is the % THD of the system having the PID damping controller and Fig-18 shows the %THD of the system having the Artificial Neural Network (ANN) instead of the PID damping controller, The percentage of THD is reduced by ANN,

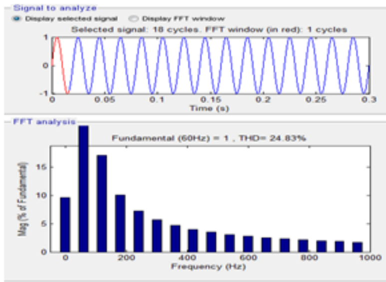


Fig-17 THD of the system having PID

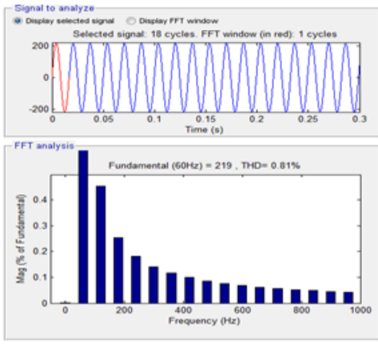


Fig-18 THD of the system having ANN

VI. CONCLUSION

This paper has presented the dynamic stability of the studied integrated system by using the STATCOM joined with PID damping controller and it is very effective to stabilize the studied system under the different operating conditions, The control scheme improves the damping stability, The voltage fluctuations of the AC bus subject to the active power variations of the studied system can also be effectively controlled by the proposed control scheme and system performance is also improved,

VII. REFERENCE

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