



Original Article

Reactive power control and optimisation of hybrid off shore tidal turbine with system uncertainties

Asit Mohanty^{a,*}, Meera Viswavandya^b, Prakash K Ray^c, Sthitapragyan Mohanty^d

^a Department of Electrical Engineering, College of Engineering and Technology, Bhubaneswar 751003, India

^b Associate Professor, CET Bhubaneswar, India

^c Department of Electrical Engineering, IIIT, Bhubaneswar 751003, India

^d Research Scholar, CET Bhubaneswar, India

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Abstract

This paper projects an isolated hybrid model of Offshore wind-diesel-tidal turbine and discusses the stability and reactive power management issue of the whole system. The hybrid system often loses its stability as it becomes prone to uncertain load and input parameters and therefore the necessity of Reactive power management becomes necessary. The overall stability of the hybrid offshore wind-diesel-tidal turbine is made possible by the management of reactive power in the hybrid system through the application of FACTS devices. And therefore the dynamic hybrid model of the DFIG and DDPMSG based offshore wind-diesel-tidal turbine is analysed for stability with different input parameters like wind and tidal energies. For detailed modelling and simulation, a small signal model of the whole hybrid system is designed and reactive power management of the system is achieved by the incorporation of a STATCOM controller. For improvement of stability and reactive power compensation of the hybrid system, GA and PSO optimised STATCOM controller is used.

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Keywords: Offshore wind-diesel-tidal hybrid system; DFIG; DDPMSG; Reactive power; STATCOM; PSO.

1. Introduction

Remote places situated far away from the main grid always remain devoid of power. Therefore it is always a challenge for the power engineers to supply adequate power to the loads situated far away. Renewable energy sources play a vital role in providing power to these localities as power can be generated near the loads in these localities. Multiple renewable energy sources are often utilised as hybrid systems in these places to boost the generating capacity and to face the uncertainty nature of renewables. Hybrid systems like wind-pv, wind-fuel cell, wind-diesel, wind-bio mass are quite common combination and are often utilised in standalone mode. In recent days wind offshore power plants are operating in different corners of the world are found a good number of research articles

are published about this technology. But in contrary the tidal energy conversion is a technology that is still in development. Combination of these two vital energy sources is a great benefit to the mankind particularly for the remote islands and all the offshore places. This hybrid energy source acts in a combined manner and produce energy for the isolated loads. The offshore wind tidal combined system can be of great benefit to the remote islands where the extension of electricity grid is a costly affair.

The combination of offshore and tidal turbines offer combined continuous power as it is a well-known fact that the renewable energies source as individual they do not produce energy continuously eradicate the intermittent power supply of the individual sources [1–5]. The isolated hybrid system uses a diesel engine which works as a backup for the combined system. During the hybrid operation the two energy sources compensate one another in order to produce energy in continuous period. Generally the wind turbine uses an in-

* Corresponding author.

E-mail address: asithimansu@gmail.com (A. Mohanty).

Nomenclature

$P, Q_{\text{DFIG/DDPMG}}$	Real power Reactive power (DFIG/DDPMG)
$P_{\text{SG}}, Q_{\text{SG}}$	Real Power, Reactive Power- (SG)
$E_{\text{M}}, \Delta E_{\text{M}}$	Electromagnetic energy and small change of Energy. (DFIG)
$\Delta Q_{\text{STATCOM}}$	Reactive generated by STATCOM
ΔQ_{COM}	Reactive Power (Compensator)
$K_{\text{A}}, K_{\text{E}}, K_{\text{F}}$	Gain Constants of Voltage Regulator, Exciter, Stabilizer
ΔV	Incremental Change in terminal Voltage
K_{α}, K_{v}	Exciter Gain, Gain Energy loop
$T_{\alpha}, T_{\text{r}}, T_{\text{s}}$	Exciter, rising, settling time const.
$X_{\text{d}}, X'_{\text{d}}$	Direct axis reactance of SG under steady state and transient
$\Delta \alpha$	Phase angle -Compensators
ΔE_{q}	Incremental Change in Internal Armature Voltage
ΔE_{fd}	Change in the Voltage of the Exciter
η	Performance Index

duction generator as it is robust in nature. In present days DFIGs are frequently used as wind turbines [6–9]. The tidal turbine functions just like the wind turbine and uses DFIG and DDPMMSG. The tidal turbine is the most predictable energy source and gives continuous power supply. The offshore wind turbine also gets continuous wind supply in comparison to wind turbine in the mainland [10–15]. The combination with the diesel backup becomes a reliable energy source for remote locations. The wind-tidal isolated hybrid systems are reliable and need low maintenance. In order to achieve optimum result there is always a need of correct size of each component of the—energy system and optimisation of energy management within the system. As the wind remains much more constant in the sea than the land, the sea proves to be advantageous for wind turbines. The tidal turbine has lot of similarities with wind turbines as far as the electrical side layout and modelling are concerned. It is also true that the speed of water currents is lower than the wind speed but the water density is more than the air density. The wind turbines function at a higher rotational speeds and lower torque than tidal in-stream turbines as the water density is higher than the air density. As tidal turbines are much more predictable they are integrated with electrical power grid in a easier way [16,17]. Areas with limited grid capacity always pose challenges before the power engineers Day by day the penetration of tidal current energy is increasing into the electrical grid system and more and more number of tidal based hybrid systems are coming to the picture. But the stability of these tidal based hybrid systems are always a challenge for the researchers. A tidal turbine generator responses to network voltage and frequency and with that it maintains electrical performance

requirements such as reactive power capability and system voltage profile [18–20].

2. Modelling of offshore wind-tidal hybrid power system

In a simplified view the hybrid system as shown in Fig. 1 composes an offshore wind turbine and a tidal turbine with power electronics based FACTS devices for reactive power compensation and enhanced power quality. The FACTS devices also help in solving the grid connection problem and storage difficulties. The hybrid system not only provides combined power to the existing loads but enhances the overall reliability of the system. The diesel generator is usually used in all the hybrid systems as back up for power production. The tidal turbine becomes comparatively predictable and reliable because of its continuous power supply capability

$$\Delta P_{\text{hybrid}} = \Delta P_{\text{wind}} + \Delta P_{\text{tidal}} \quad (1)$$

$$\Delta Q_{\text{DDPMMSG}} + \Delta Q_{\text{DFIG}} = \Delta Q_{\text{SG}} + \Delta Q_{\text{COM}} \quad (2)$$

When connected to the load the reactive power balance equation becomes as in Fig. 2

$$\Delta Q_{\text{DDPMMSG}} + \Delta Q_{\text{DFIG}} + \Delta Q_{\text{L}} = \Delta Q_{\text{SG}} + \Delta Q_{\text{COM}} \quad (3)$$

The system terminal voltage is highly affected by the reactive power balance equation and it can be summarised as

$$\Delta V(s) = \Delta Q_{\text{SG}}(s) + \Delta Q_{\text{COM}}(s) - \Delta Q_{\text{DDPMMSG}}(s) - \Delta Q_{\text{DFIG}}(s) - \Delta Q_{\text{L}}(s) \quad (4)$$

2.1. Modelling of offshore-wind turbine and tidal turbine (DFIG)

DFIG is a wound rotor asynchronous generator where power flows between the rotor and grid through AC/DC/AC converters. Single line diagram of DFIG is shown in Fig. 3 where the supply side converter keeps the DC link voltage constant without considering the direction of rotor power flow.

Depending on the stator flux vector position the induction machine is controlled in synchronous rotating dq axis frame. The active and reactive power control has been realised by controlling I_{qr} and I_{dr} through the rotor side converter. The diesel engine as a conventional DG unit manages active and reactive power in high load demand. Reactive power control of the output is done by separate PI controllers and the outer loop compares the voltage of generator DFIG with that of reference voltage.

$$Q_{\text{DFIG}} = \frac{L_{\text{m}}}{L_{\text{ss}}} V_{\text{I}} I_{\text{dr}} - \frac{V_{\text{I}}^2}{\omega_{\text{s}} L_{\text{ss}}} \quad (5)$$

The linearised form of the reactive power of proposed DFIG can be calculated as

$$\text{DFIG}(s) = K_{\text{f}} \Delta I_{\text{dr}}(s) + K_{\text{e}} \Delta V(s) \quad (6)$$

where $K_{\text{f}} = \frac{L_{\text{m}} V_{\text{I}}}{L_{\text{ss}}}$ and $K_{\text{e}} = \frac{L_{\text{m}} I_{\text{dr}}}{L_{\text{ss}}} - \frac{2 V_{\text{I}}}{\omega_{\text{s}} L_{\text{ss}}}$

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