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ANALYSIS OF MVDC OFFSHORE WIND FARM DISTRIBUTION SYSTEM

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Abstract: Offshore wind farms are becoming more popular because of advantages such as availability of higher and uniform wind speeds, availability of the large sea area and proximity to major load centres. Two types of wind turbine systems for wind power generation exist. Mainly DFIG (30% speed variation) and PMSG (100 % speed variation) generators are used in wind farms. To evaluate any power system network, load flow analysis is necessary. But traditional load flow methods such as the GS and NR-techniques fail to meet the requirements in both performance and robustness aspects of radial connected wind farm distribution systems. Therefore in this work, the direct approach algorithm is used for wind farms in which generators are modelled as PQ bus and transmission line modelled using π model in the algorithm. Basically two types of configuration are possible Medium Voltage AC (MVAC) and Medium Voltage DC (MVDC) offshore WFDS. Due to lower losses in MVDC offshore WFDS, a today lot of research is going on to design MVDC offshore WFDS. The results are presented for both MVAC and MVDC based offshore wind farm distribution system using MATLAB programming. Finally, a performance comparison has been made between the MVAC and MVDC based offshore Wind Farm Distribution System (WFDS).
Keywords: wind energy; PMSG; MVAC; MVDC; Wind Farm Distribution System; Direct load algorithm

I. INTRODUCTION

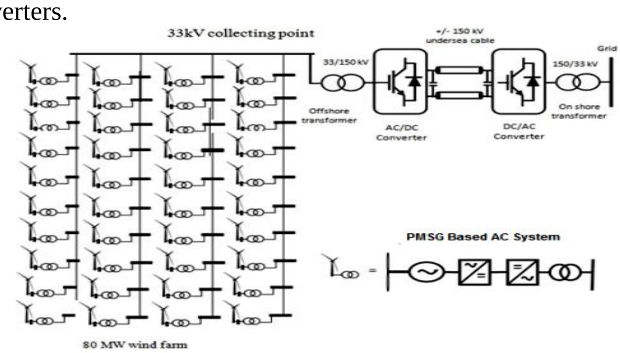
Wind energy is the world's fastest growing renewable energy source. Electricity generation using wind energy has been well recognized as environmentally friendly, socially beneficial, and economically competitive for many applications. As the wind power technologies evolve from one to another breakthrough, the wind power plants continue its increasing penetration in the power system.

In recent years offshore wind farms are more popular because of the following advantages.

- The wind resource in offshore is generally much greater, thus generating more energy from fewer turbines.
- Availability of uniform wind speeds i.e. no turbulence in the wind (turbulence in wind may damage turbine blades).
- Most of the world's largest cities are located near a coastline. Offshore wind is suitable for large scale development near the major demand centers, avoiding the need for long transmission lines.
- Availability of large sea area.

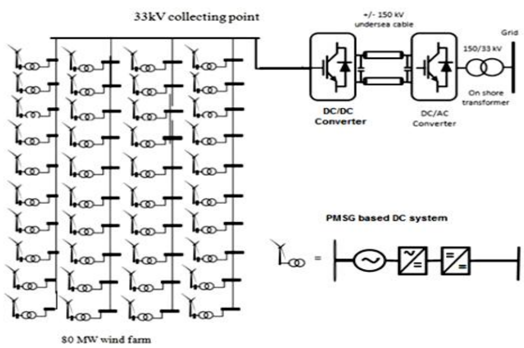
II. SYSTEM MODELLING

Large offshore wind farms located far away from their grid connection point require HVDC to connect to shore to reduce cable losses and decrease reactive power requirements. Figure 1 shows a typical offshore wind farm using an HVDC interconnector requires individual transformers (usually located in the tower of the generator) to boost the low voltage output of a wind generator to medium voltage (MV) levels in case of AC system (MVAC) undersea cables connect to an offshore converter station to collect energy from the wind farm, a high-voltage (HV) transformer to boost the voltage, and an HVDC converter. The system under study considers PMSG for the offshore variable speed WECS and consisting of two back-back converters.



"Figure 1 MVAC offshore wind farm distribution system connected to the grid"

Figure 2 shows MVDC distribution system is connected to grid via DC-DC converter at offshore and at onshore platform by using DC-AC converter and step down transformer.



"Figure 2 MVDC offshore wind farm distribution system connected to the grid"

III. WIND TURBINE MODELLING

The wind turbine extracts power from the wind and then converts, it into mechanical power. [3]The variable wind speed available to the wind turbine can be represented by the following equations

$$v_w(t) = v_{wa}(t) + v_{wr}(t) + v_{wg}(t) + v_{wt}(t) \quad ..(1)$$

where $v_w(t)$ - instantaneous wind speed

$v_{wa}(t)$ - Average wind speed

$v_{wa}(t)$ - Ramp component

$v_{wg}(t)$ - Gust component

$v_{wt}(t)$ - Turbulence component.

For the analysis, wind speed is taken as continuous by neglecting the gust, ramp and turbulence components. The power available in the wind is given by

$$P_v = \frac{1}{2}\rho A V_w^3 \quad .....(2)$$

where ρ is the air density

A is swept area

V_w is velocity of wind

The wind turbine can recover only a part of that power, which is given by

$$P_{mech} = \frac{1}{2}\rho\pi R^2 V_w^3 C_p \quad ....(3)$$

where R is the radius of the wind turbine and C_p is the power coefficient

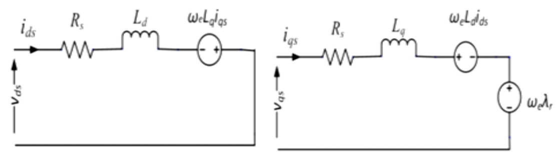
Power coefficient is a dimensionless parameter that indicates the effectiveness of the wind turbine in the transformation of kinetic energy of the wind into mechanical energy.

IV. STEADY STATE MODELLING OF PMSG

PMSG can generate power at any wind speed between cut in and cut out speed. Here converter loss and efficiency calculation is carried out from standard datasheets (Appendix) and from [5] and The steady state model generally used for the PMSG as shown in Figure 3 is the d-q axes 'Park' model. theory of the space vector gives the dynamic equations of the stator voltages as below.

$$V_{sd} = R_s I_{sd} + \frac{d\varphi_{sd}}{dt} - \omega_e \varphi_{sq}$$
$$V_{sq} = R_s I_{sq} + \frac{d\varphi_{sq}}{dt} + \omega_e \varphi_{sd} \quad ....(4)$$

where V_{sd} and V_{sq} are the d – q components of the stator voltages respectively, I_{sd} and I_{sq} are the d – q components of the stator currents respectively, R_s is the phase resistance of the stator winding.



"Figure 3 Steady state PMSG model in the rotor reference frame"

The stator fluxes are given by:

$$\varphi_{sd} = L_d I_{sd} + \lambda_r$$
$$\varphi_{sq} = L_q I_{sq} \quad ....(5)$$

where, L_d and L_q are the d – q components of the stator inductances respectively

λ_r is the flux linkage of the permanent magnet

$\omega_e = P\omega_m$ is the rotor speed in elec. rad/s and P is the number of pole pairs.

Combining equations (.4) and (.5),

$$V_{sd} = R_s I_{sd} + L_d \frac{dI_{sd}}{dt} - \omega_e L_q I_{sq}$$
$$V_{sq} = R_s I_{sd} + L_q \frac{dI_{qs}}{dt} + \omega_e L_d I_{sd} + \omega_e \lambda_r \quad ....(6)$$

The stator active and reactive powers are given by the equations (7):

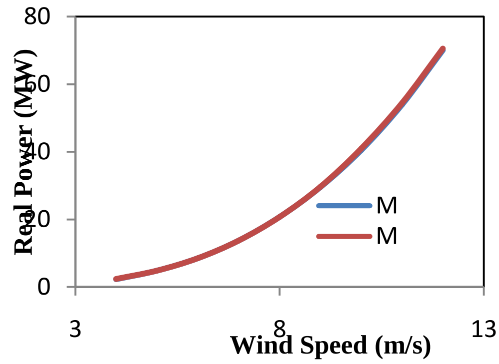
$$P_s = \frac{3}{2}(V_d I_d + V_q I_q)$$
$$Q_s = \frac{3}{2}(V_q I_q - V_d I_q) \quad ....(7)$$

In PMSG, Q_s can be maintained zero by using the machine side converter. So it is assumed to be zero. Therefore $Q_s = 0$

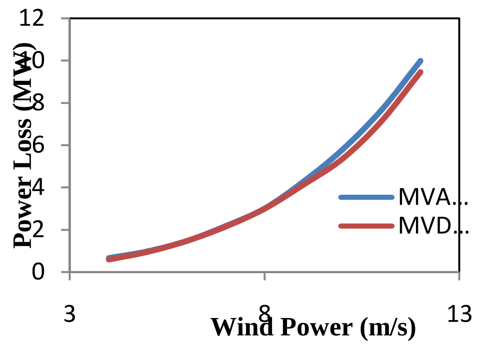
Finally, the efficiency of the machine can be obtained as

$$\eta = \frac{P_s}{P_{mech}} \quad ....(8)$$

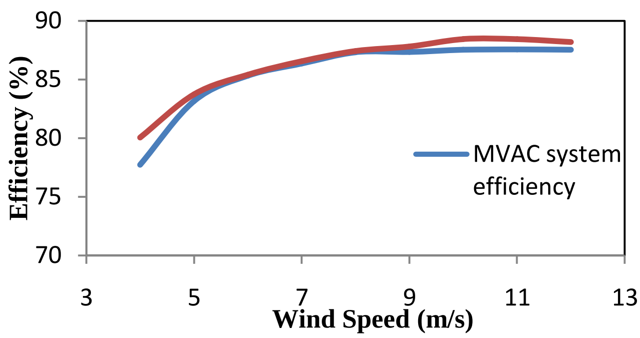
V. RESULT



"Figure 4 Real Power Generated"



"Figure 5 Real power losses"



"Figure 6 Efficiency"

VI. CONCLUSION

The steady state performance analysis of 80 MW of PMSG based Medium Voltage Alternating Current (MVAC) offshore wind farm distribution system and Medium Voltage Direct Current (MVDC) offshore wind farm distribution system connected to a High Voltage DC (HVDC) transmission line are investigated. From above conclusions it is identified that for offshore wind application MVDC WFDS is superior to MVAC WFDS. MVDC offshore WFDS has also advantages like elimination of large AC transformers, reduction of the size and weight of the cable connection, reduction of weight of offshore platforms.

VII. APPENDICES

7.1 Wind turbine parameters:
Turbine rating – 2.5 MW
Rotor diameter - 80 m
Turbine height - 150 m
Hub height - 90m
Distance from offshore – 100 km
7.2 33 kV XLPE cable parameters:
Resistance- 0.075 Ω/km (for MVAC) and 0.0558 Ω/km (for MVDC)
Inductance- 0.33 mH/km (only for MVAC)
Capacitance- 0.2 µF/km (only for MVAC)

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