Chapter 08 Doubly-Fed Induction Generator Based WECS

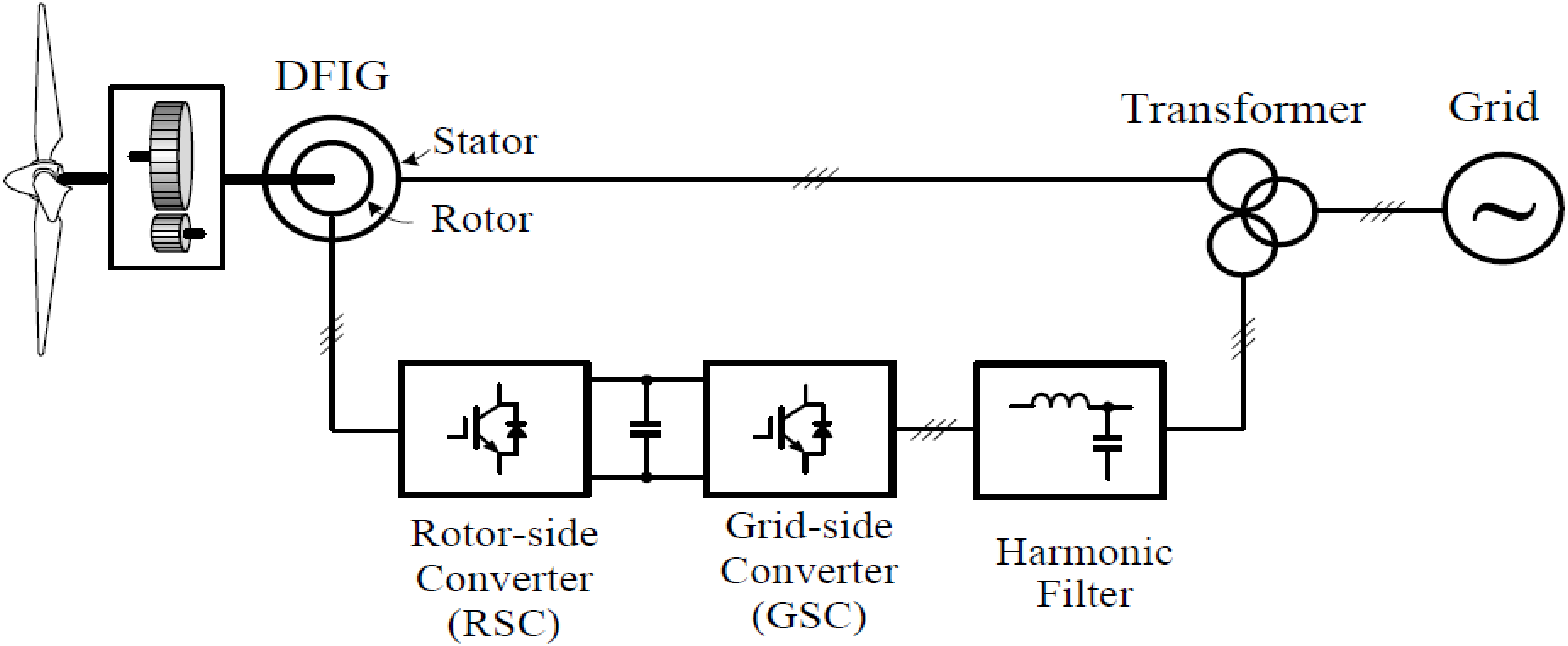
8.1 Introduction

Q. Why Doubly Fed Induction Generator (DFIG) widely accepted in today's wind energy industry?

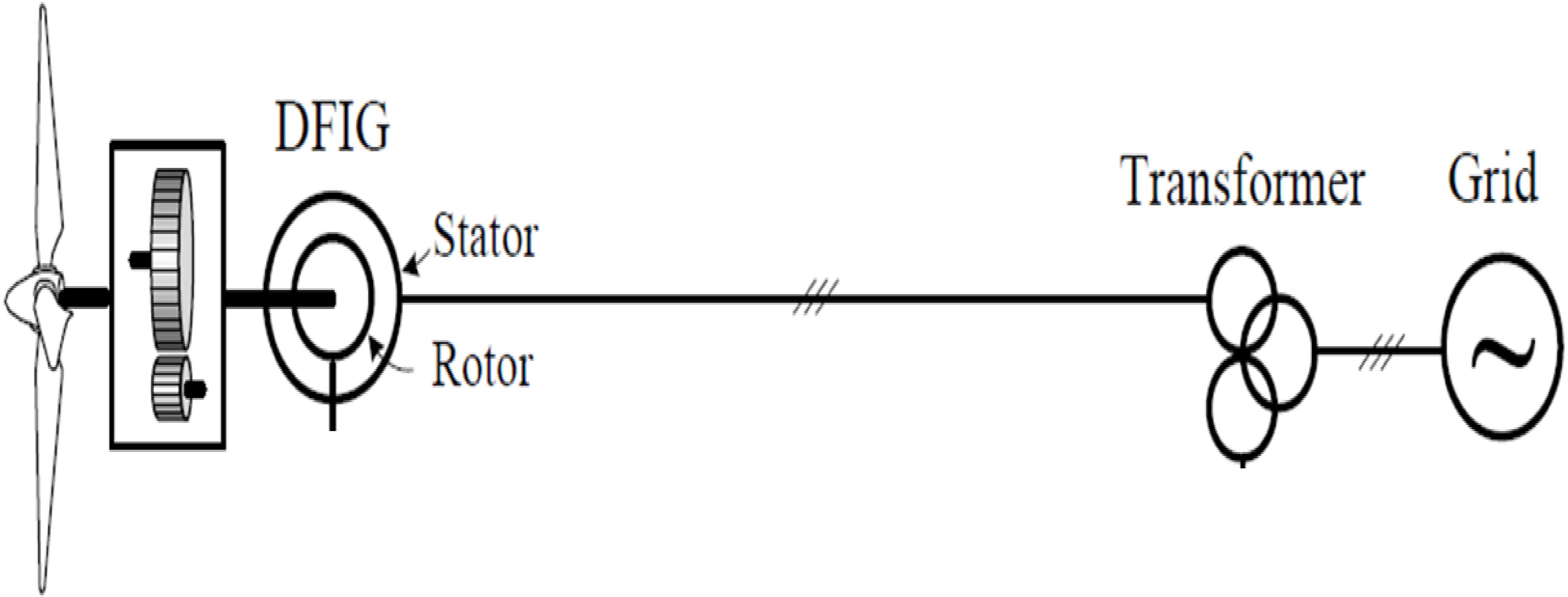
DFIG’s features make it prominent for widely acceptance in today’s wind energy industry.

DFIG’s features

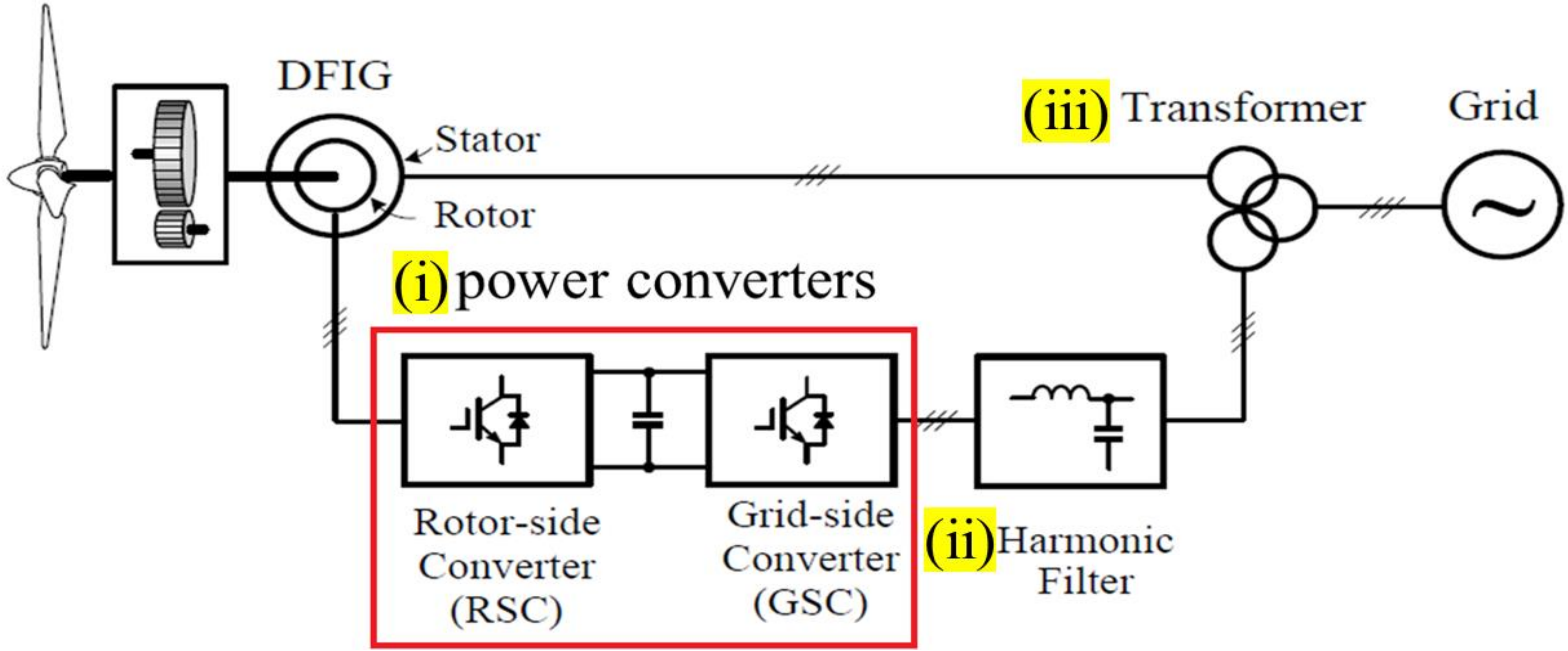
DFIG is a wound rotor induction generator. Rotor circuit is controlled by external devices to achieve variable speed operation.



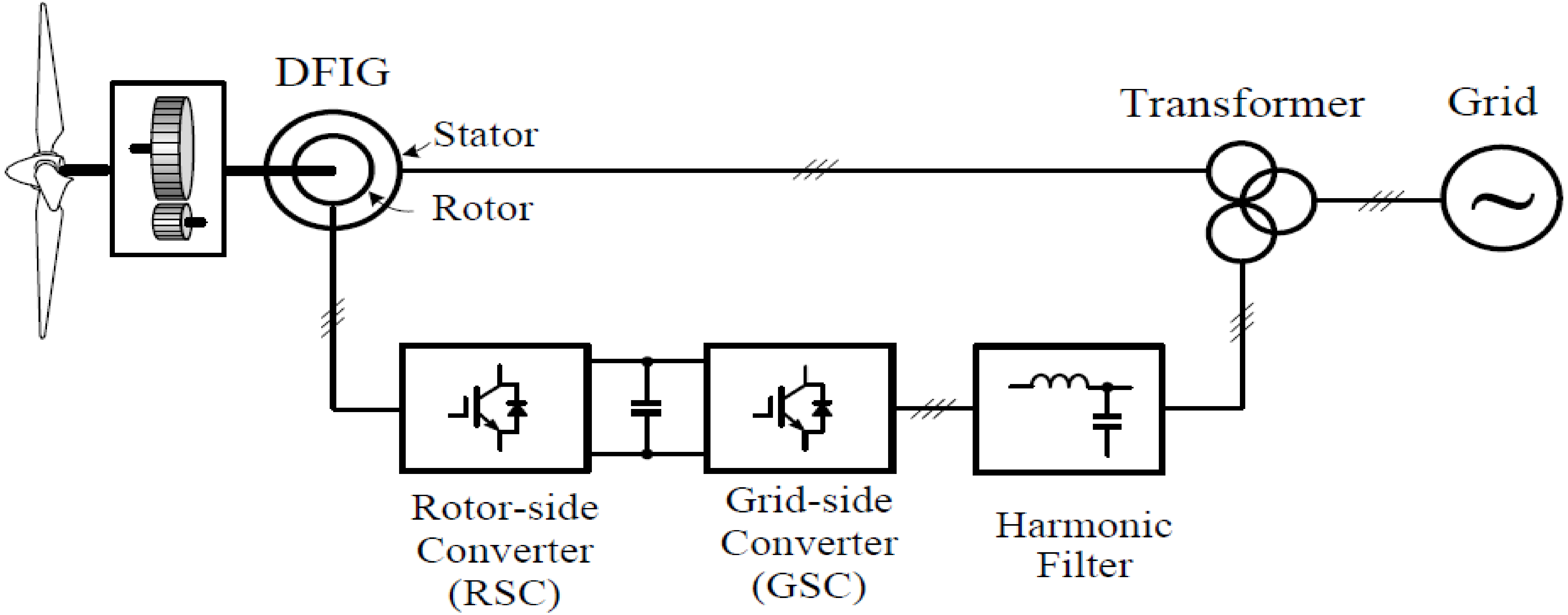
Stator of generator is connected to grid through a transformer



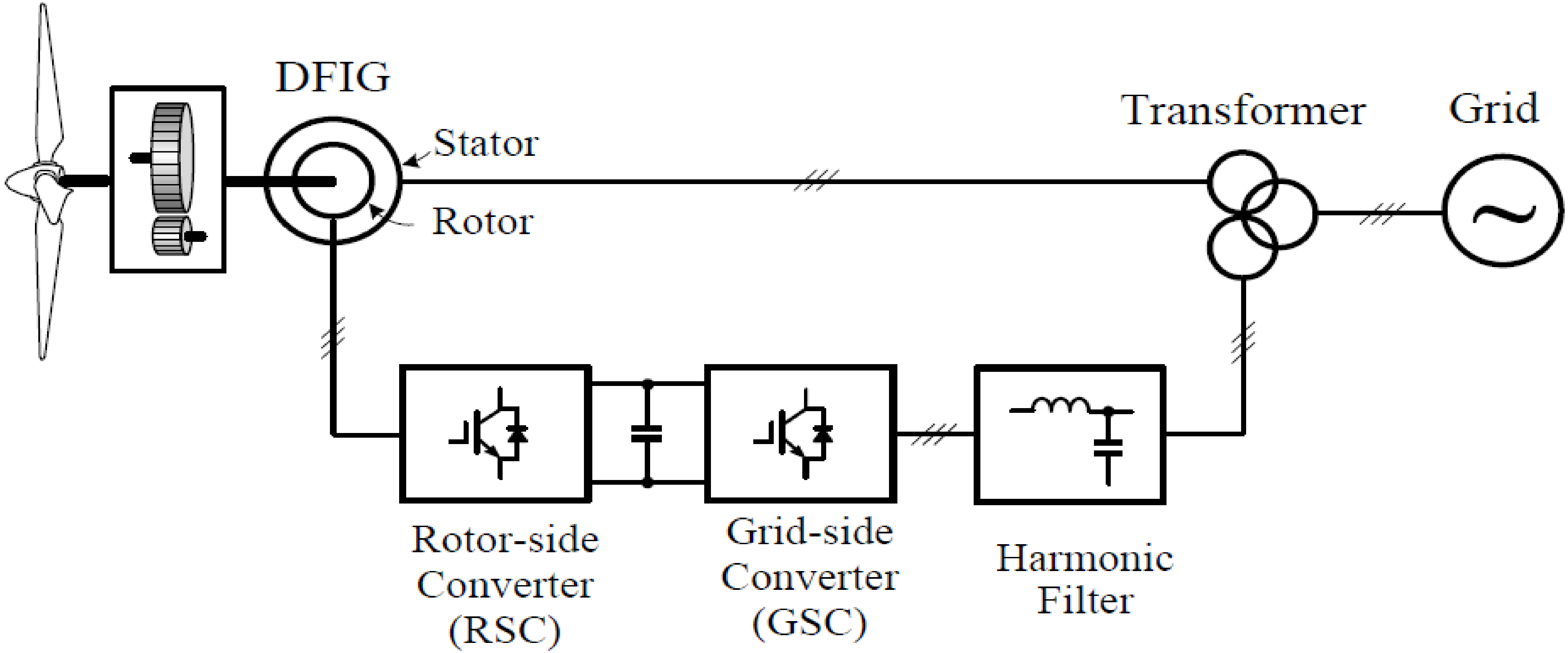
Rotor is connected to grid through (i)power converters, (ii)harmonic filter & (iii) transformer.



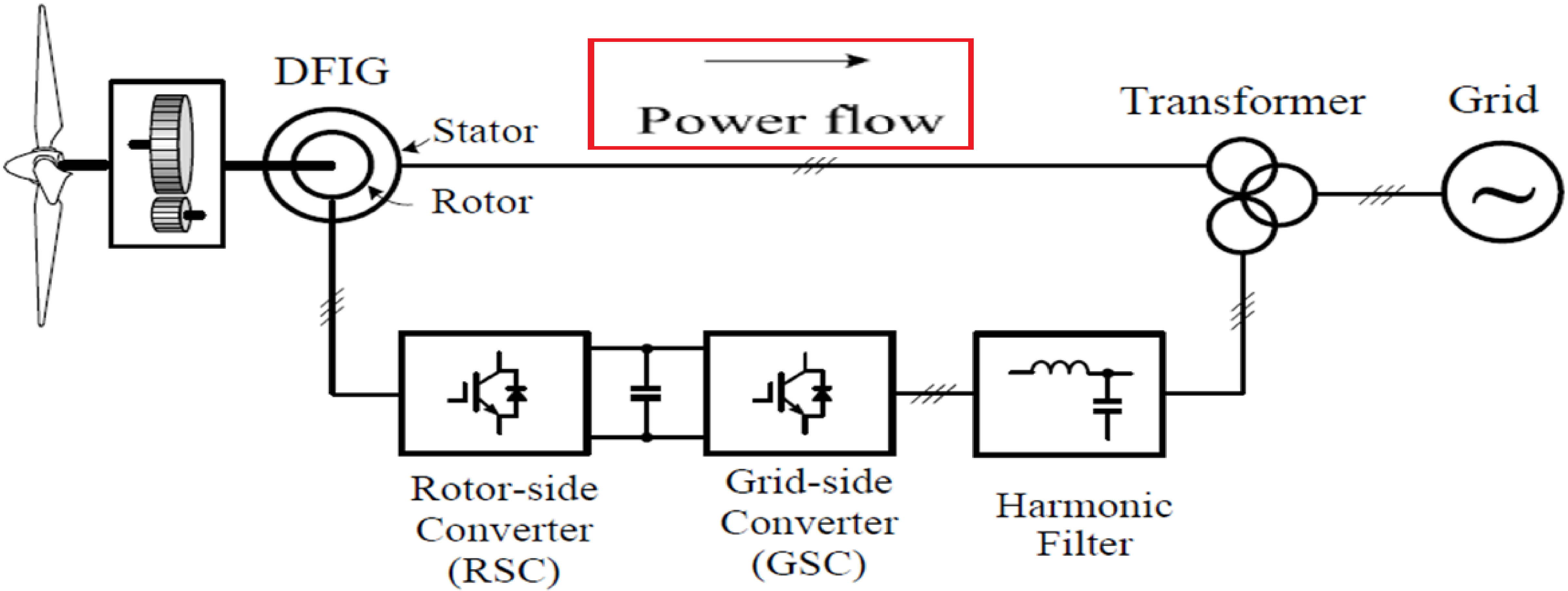
Power rating for DFIG is normally in range of a few hundred KW to several MW



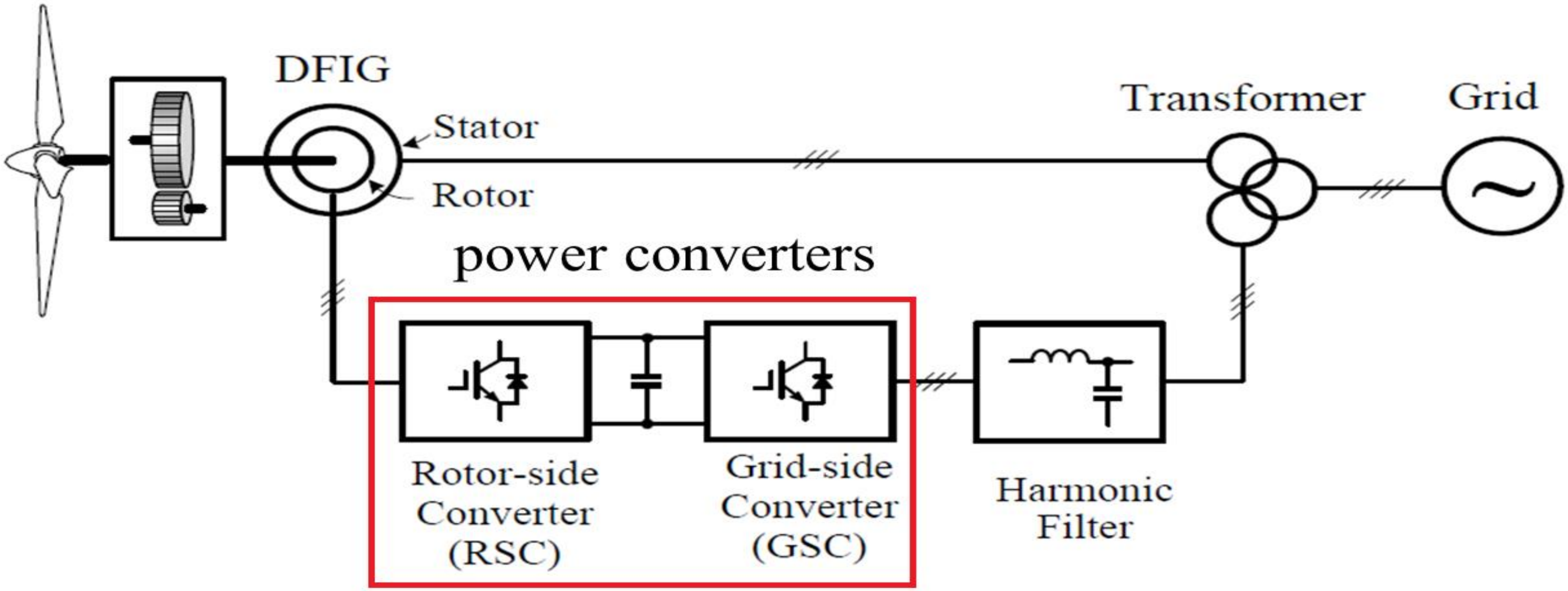
Q. Power flow in stator circuit is unidirectional?



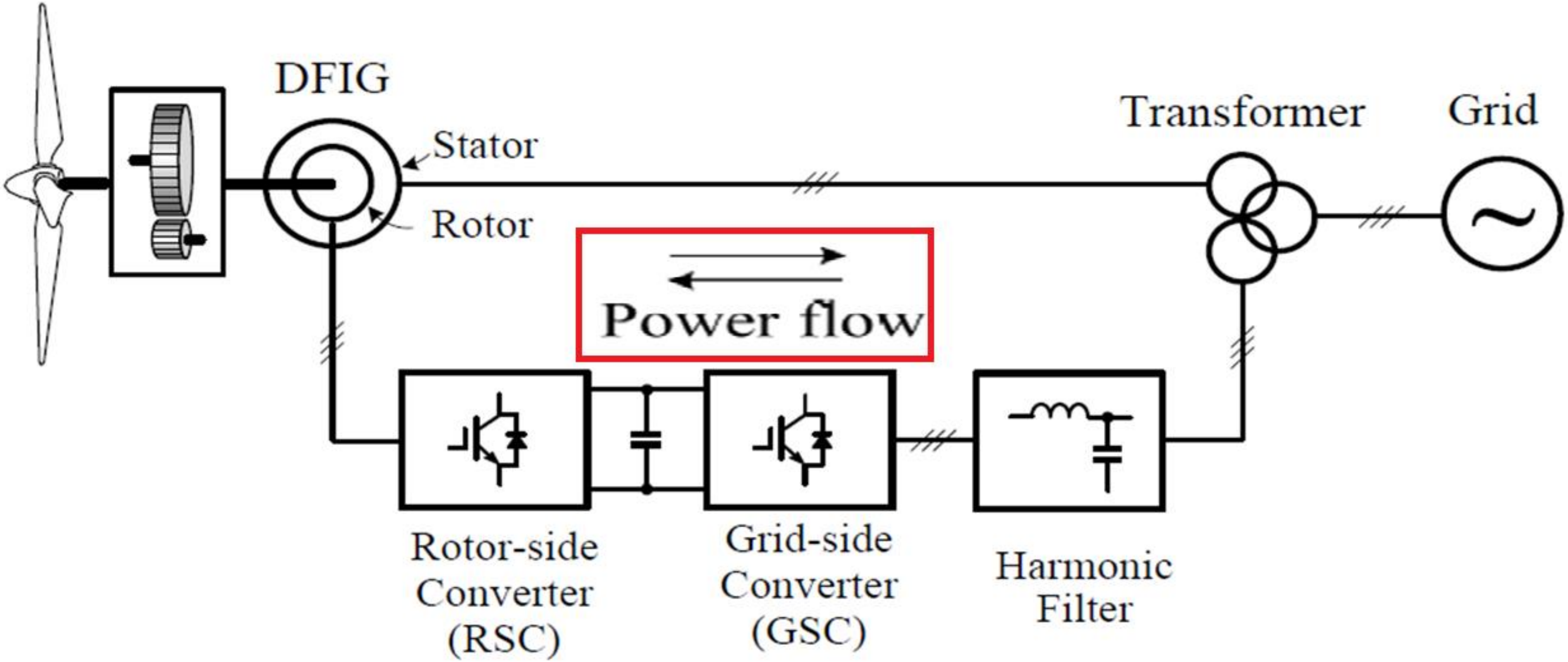
Stator of generator delivers power from wind turbine to grid & therefore power flow is unidirectional.



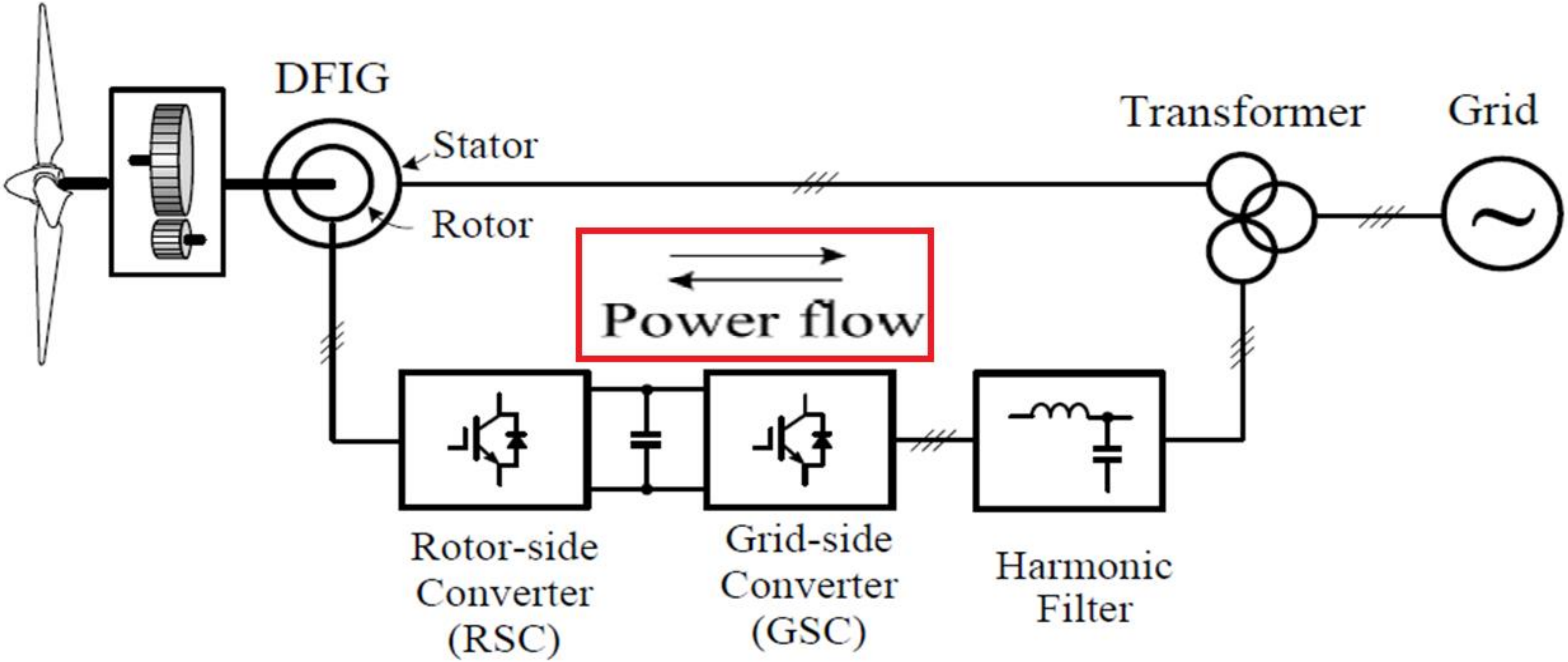
Q. Power flow in rotor circuit is bidirectional?



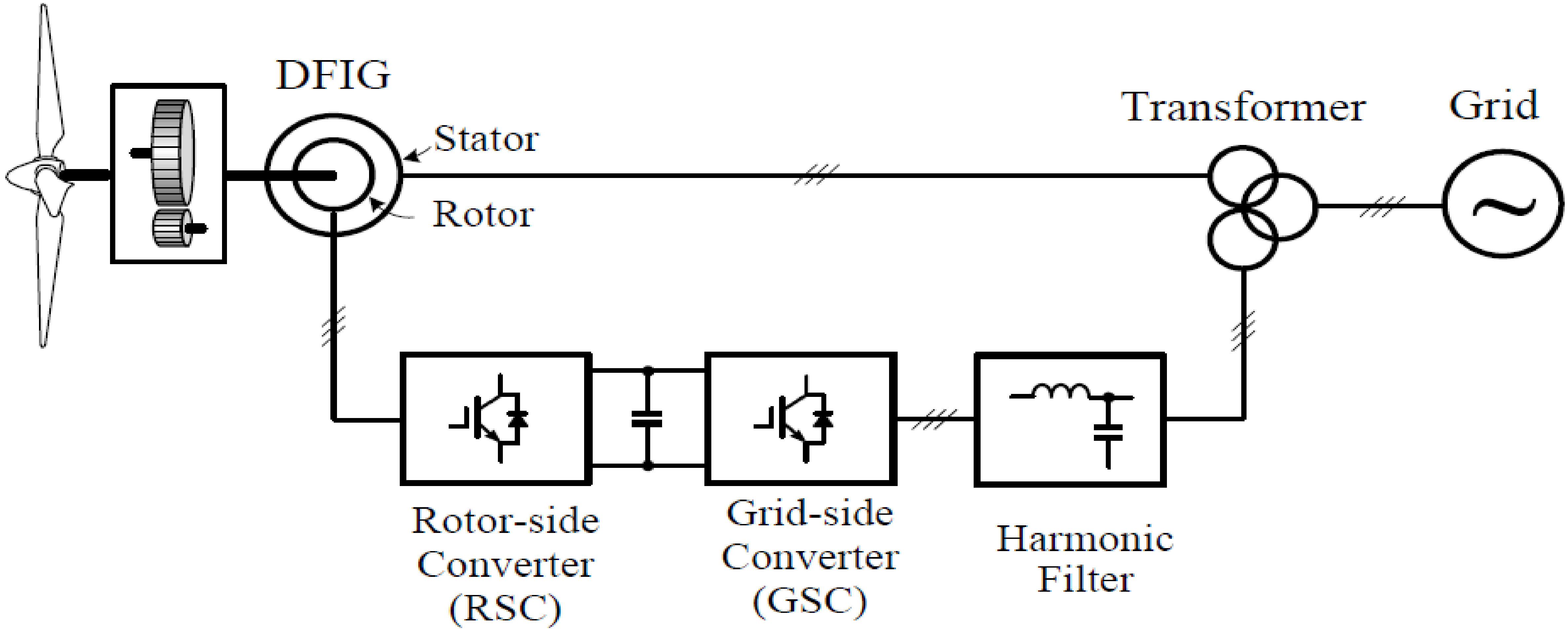
Power flow in rotor circuit is bidirectional, depending on operating conditions.



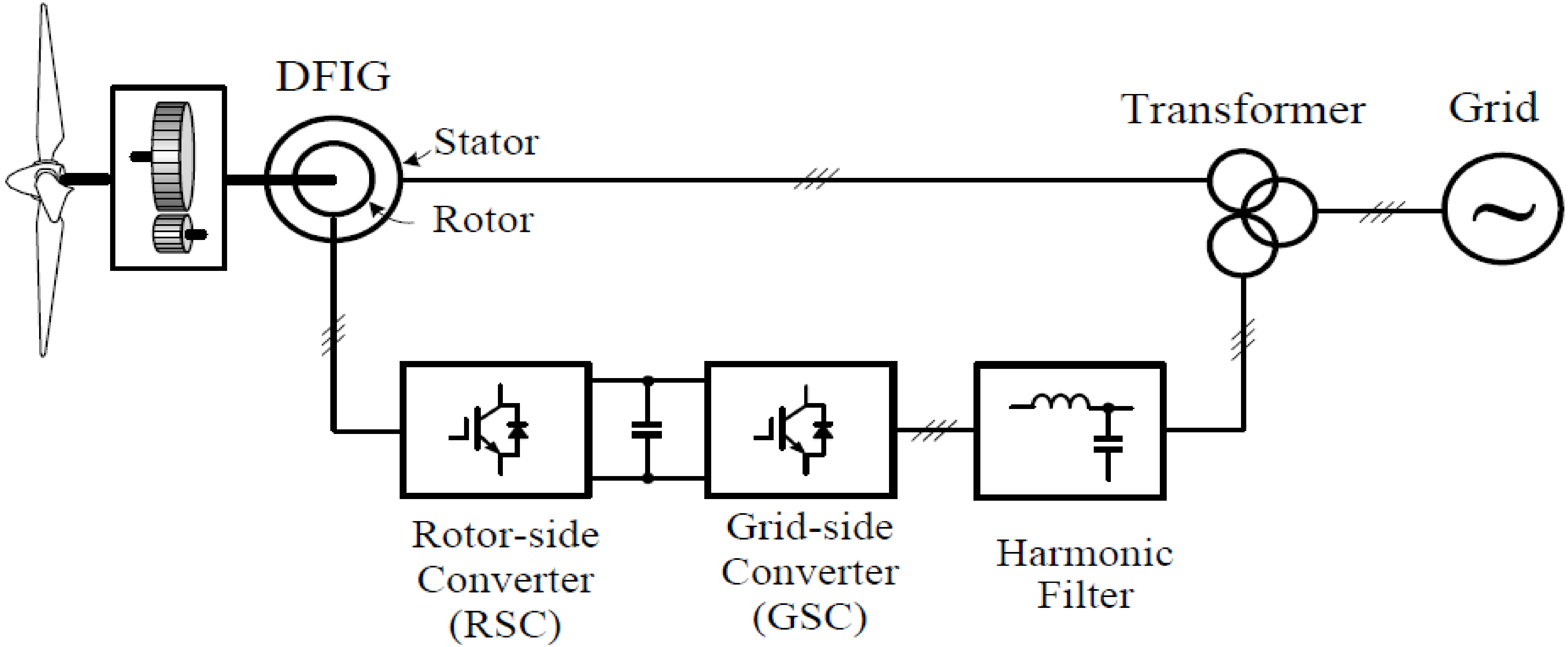
Power can be delivered from rotor to grid & vice versa through Rotor-side Converter (RSC) & Grid-side Converter (GSC).



Power rating of converters in DFIG based WECS is reduced in comparison to WECS with full-capacity converters?

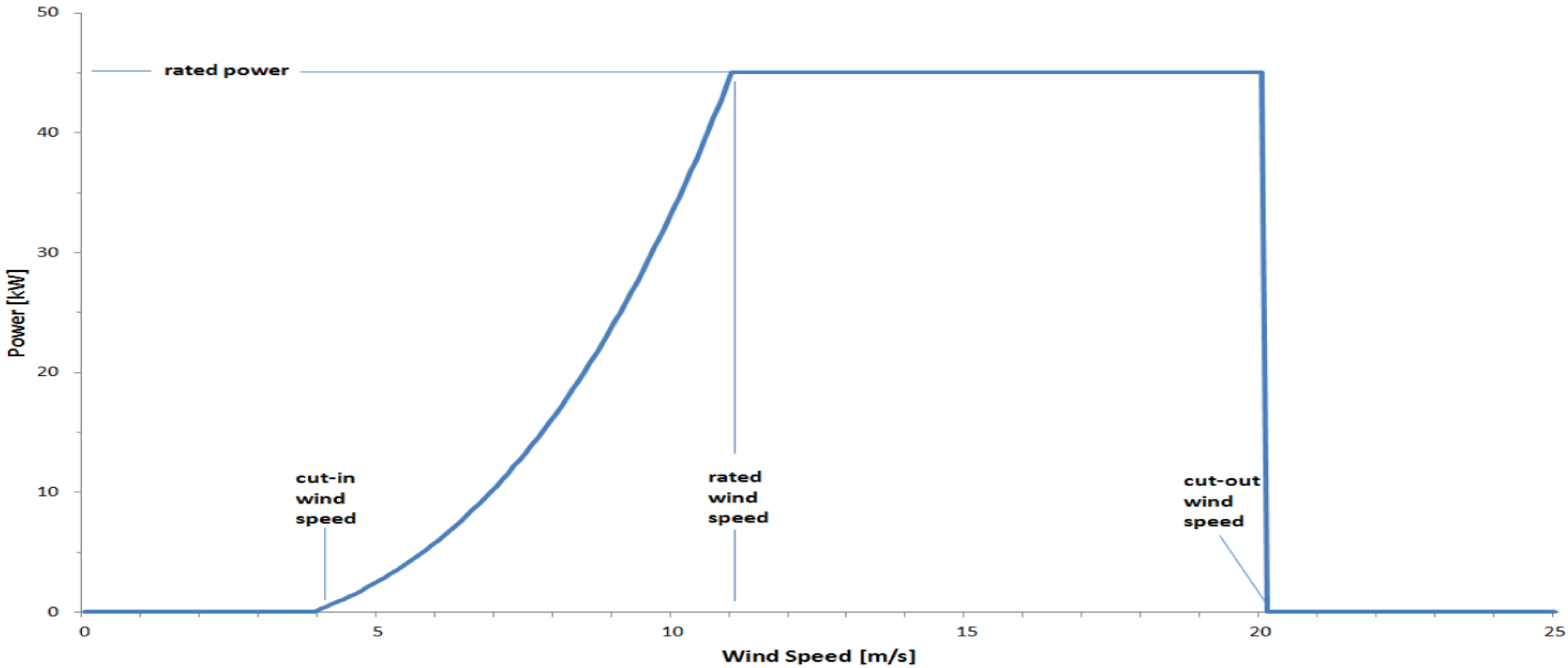


Since maximum rotor power=30% of rated stator power:



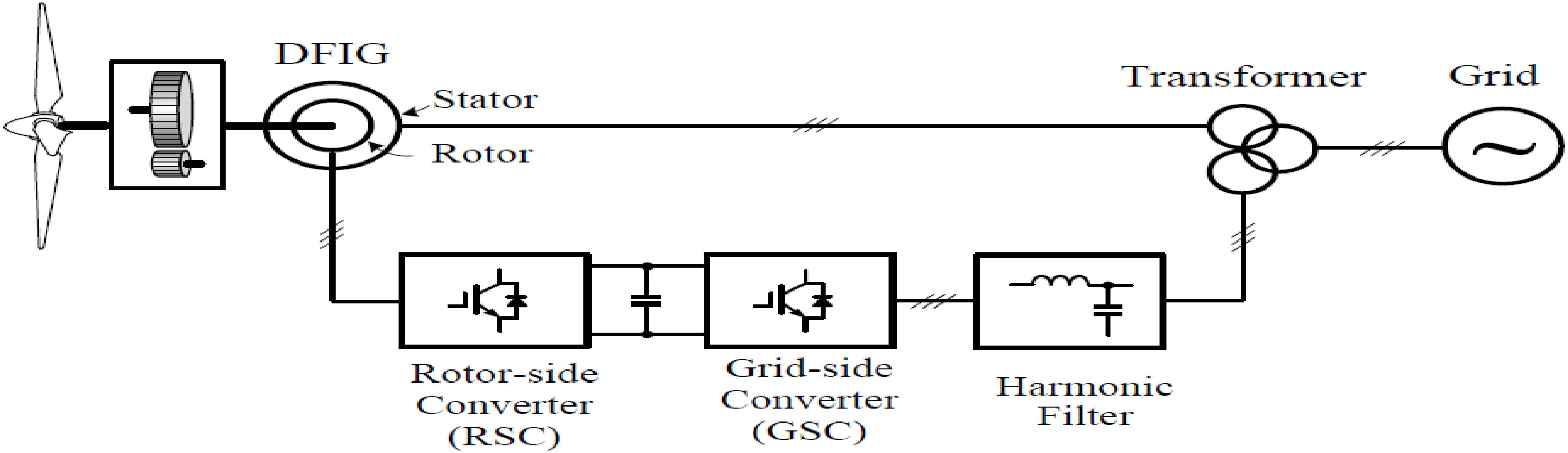
DFIG versus fixed speed WECS

With variable speed operation, a DFIG based WECS can harvest more energy from wind than a fixed speed WECS of same capacity when wind speed is below its rated value.



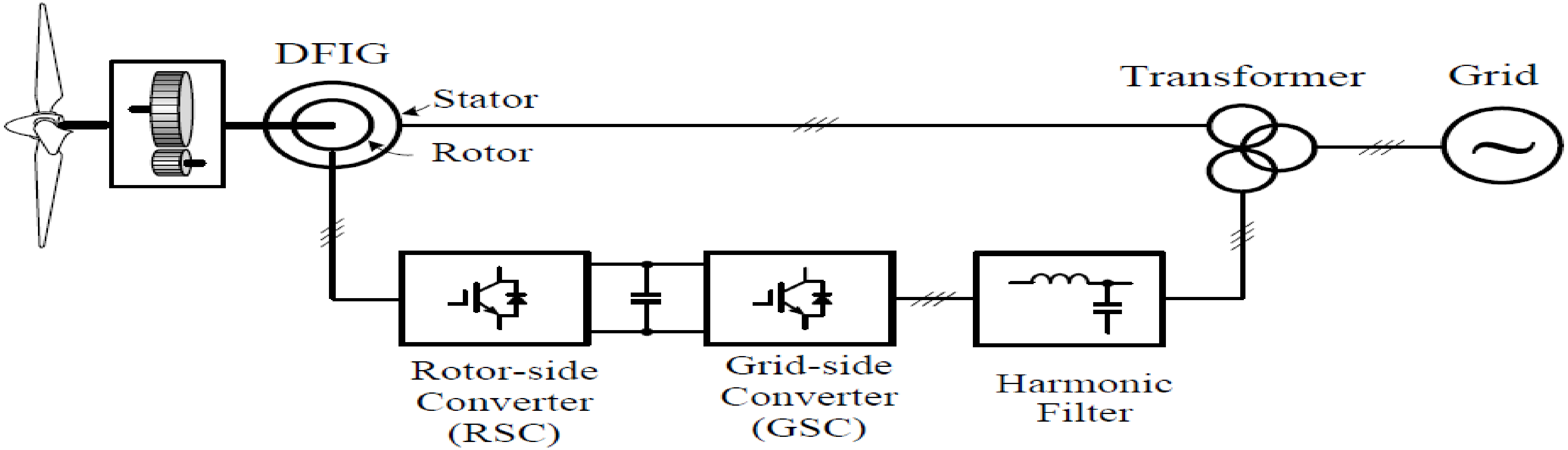
Cost of power converters & harmonic filters is lower than that in WECS with full-capacity converters.

- Power losses in converters are also lower, leading to improved overall efficiency.



System can also provide leading or lagging reactive power to grid without additional devices.

- These features have made DFIG wind energy system one of the preferred choices in wind energy market.



In this chapter, we shall study:

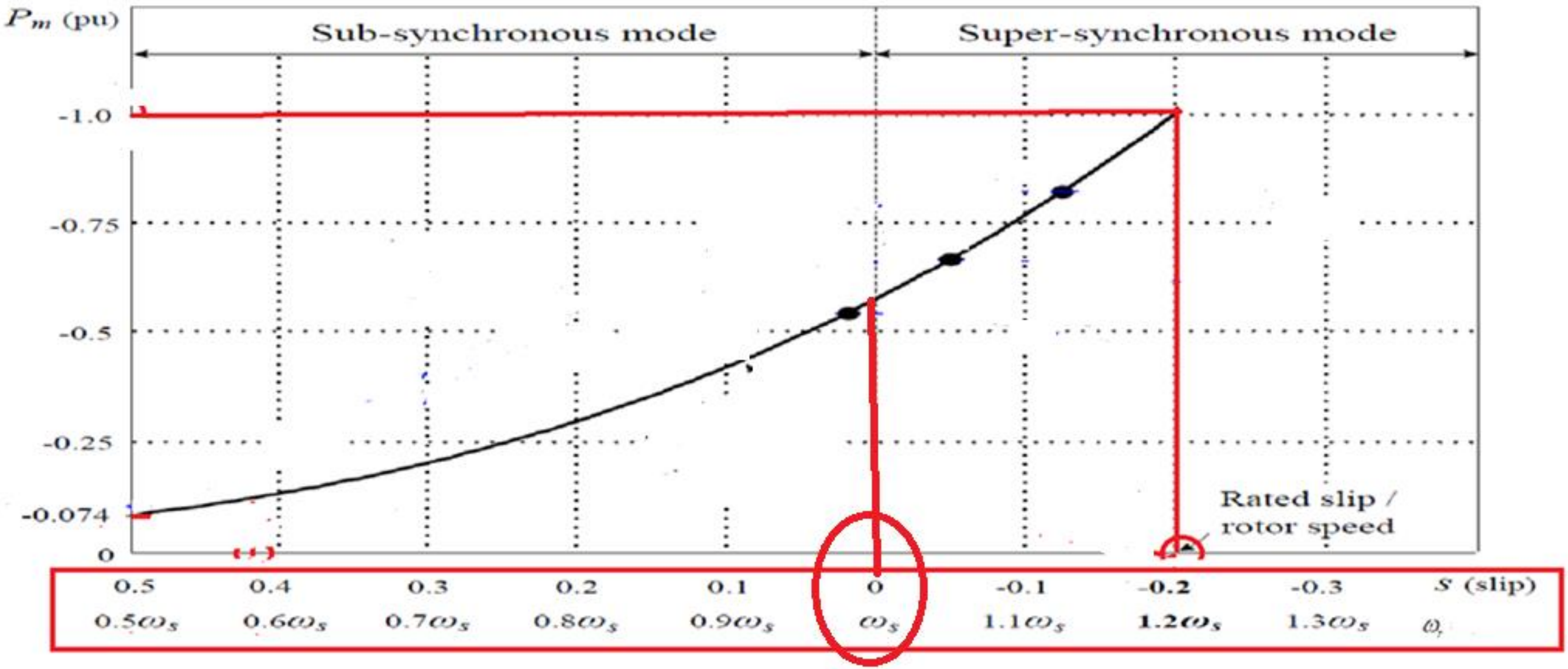
1. Steady-state analysis for DFIG wind energy system
2. Dynamic behaviour of system with investigation of Stator Voltage Oriented Control (SVOC).
3. Case studies to understand:

- principle &
- operation of system.

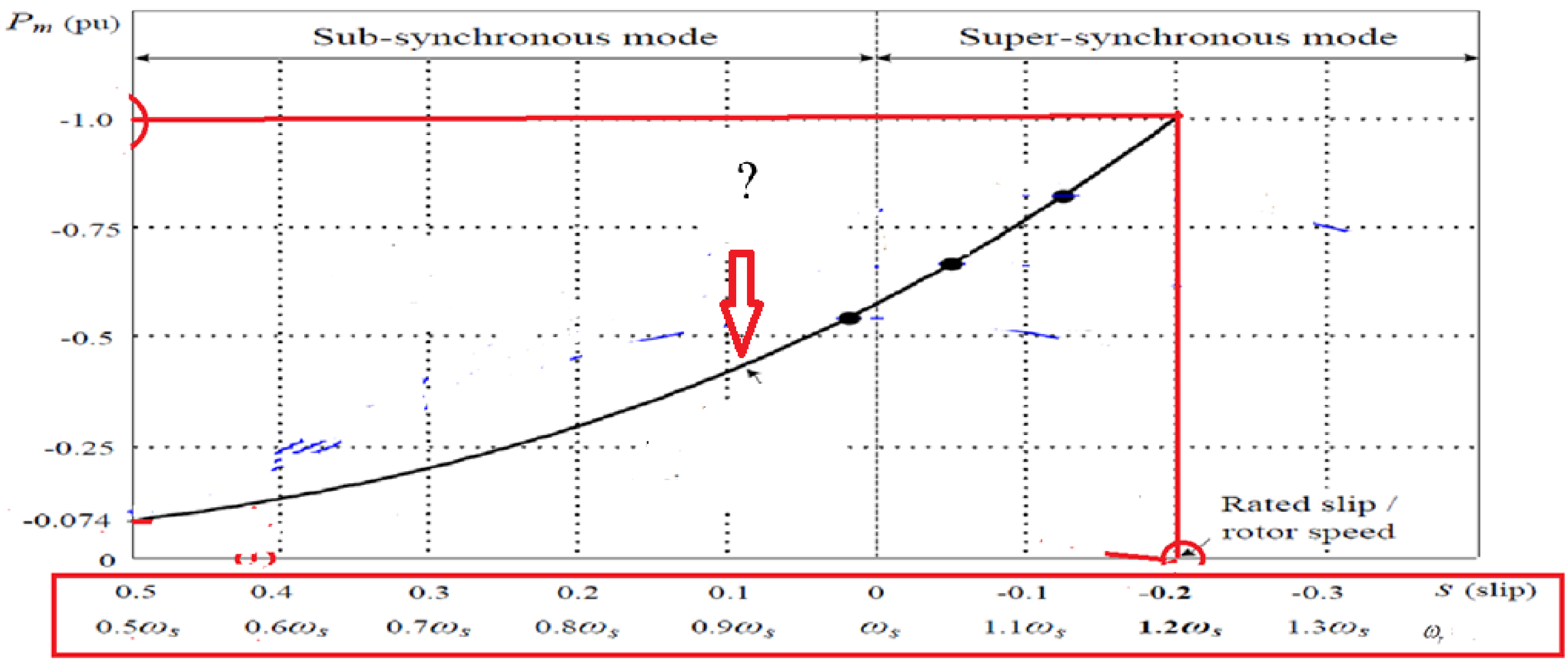
8.2 Super & Sub-synchronous Operation of DFIG

Q. What should be value of slip between sub-synchronous & super-synchronous modes?

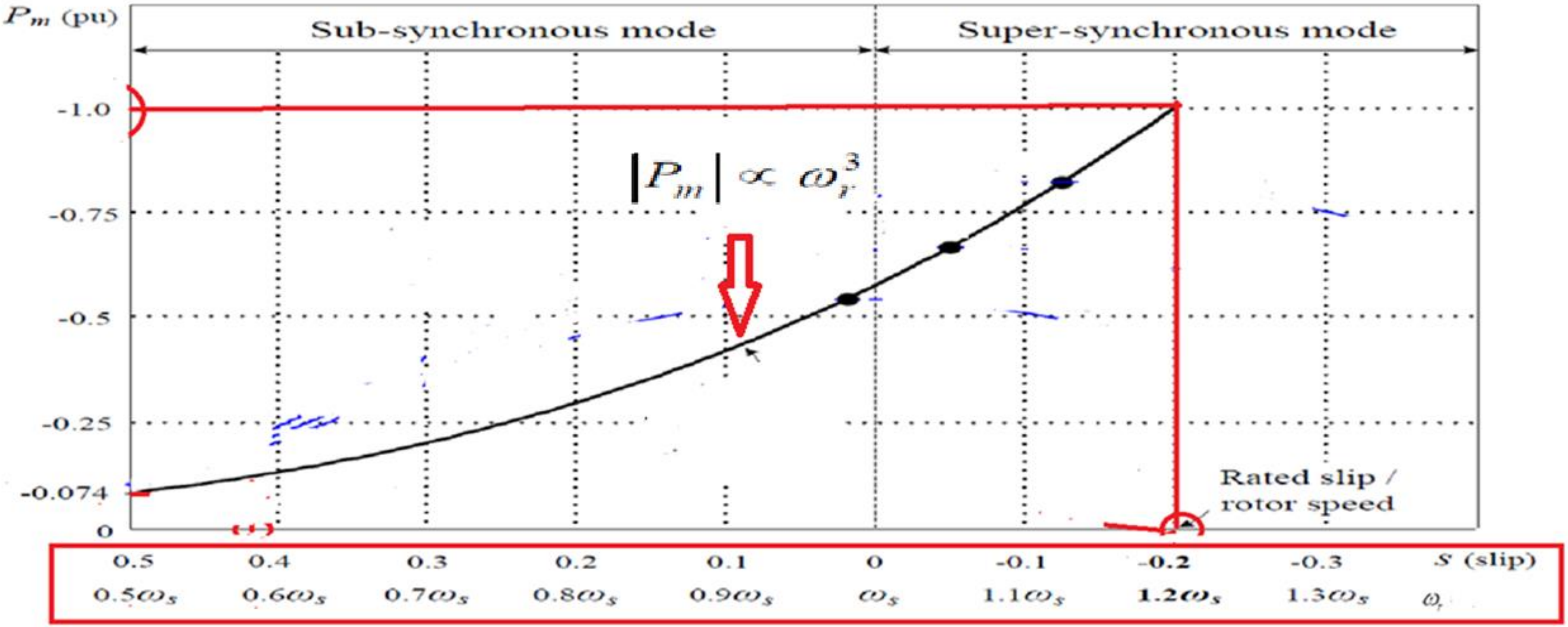
Ans. Slip=0 between sub-synchronous & super-synchronous modes



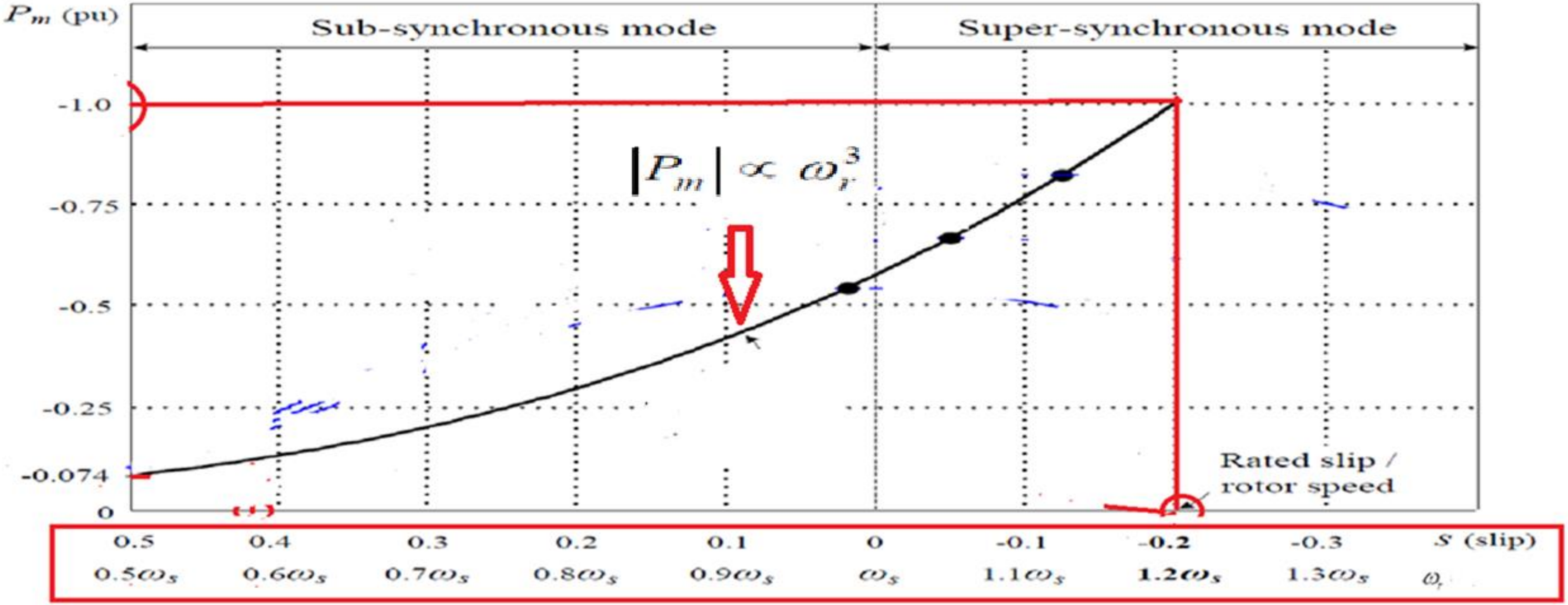
Write an equation for this curve?



Equation for the curve

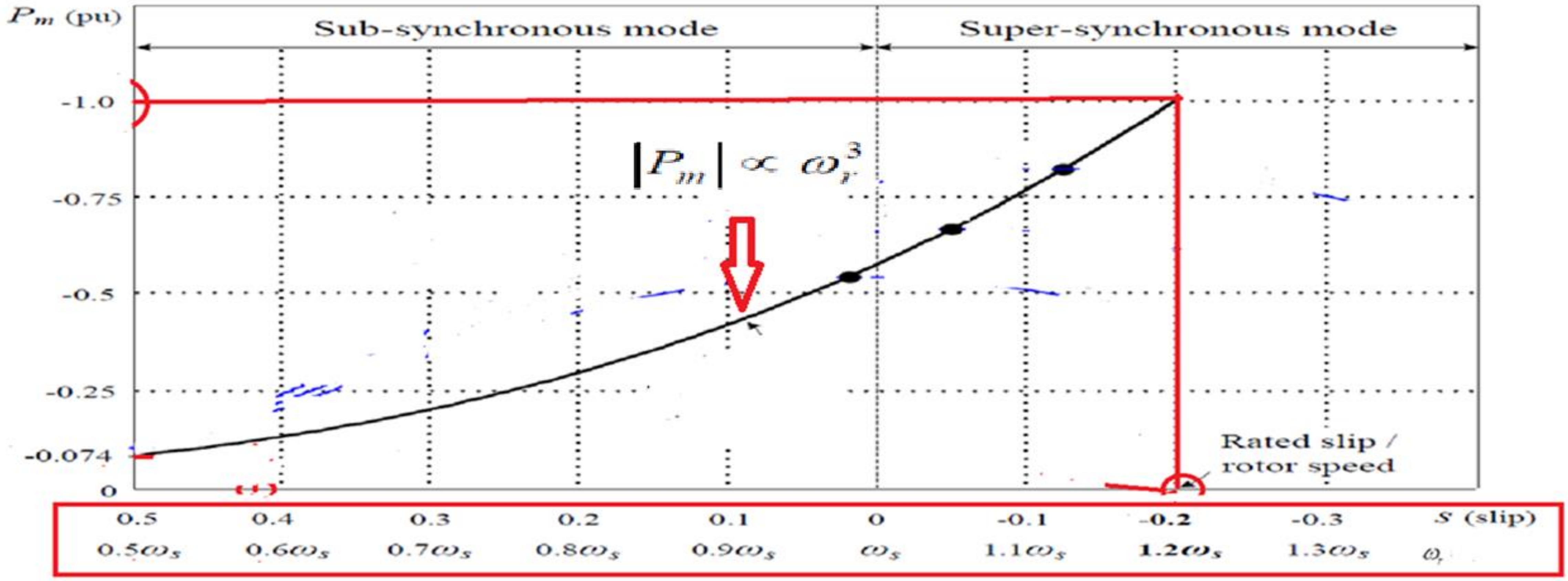


Q. Obtain ω_r in terms of slip(s) & stator angular frequency ω_s as shown in curve?

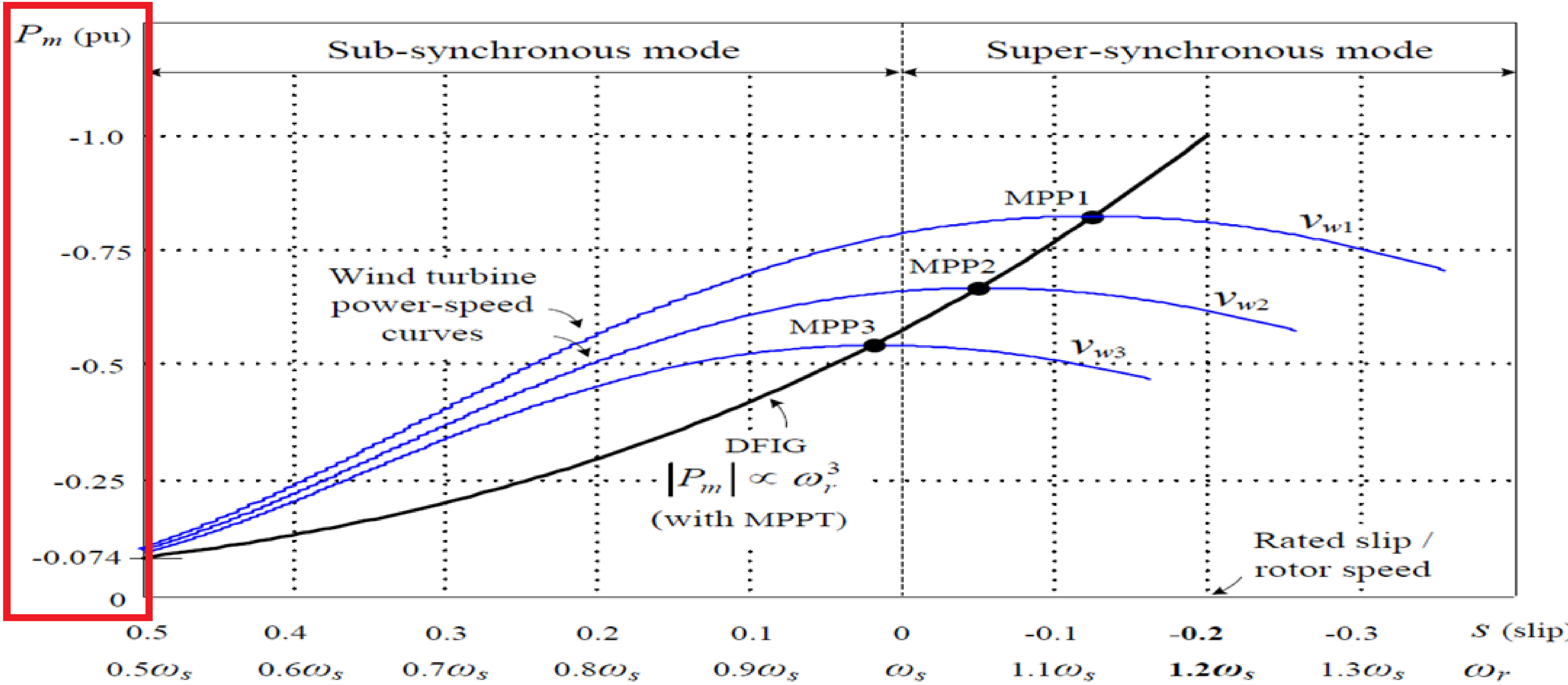


Answer: ω_r in terms of slip(s) & stator angular frequency ω_s

$$\omega_r = (1 - s)\omega_s$$

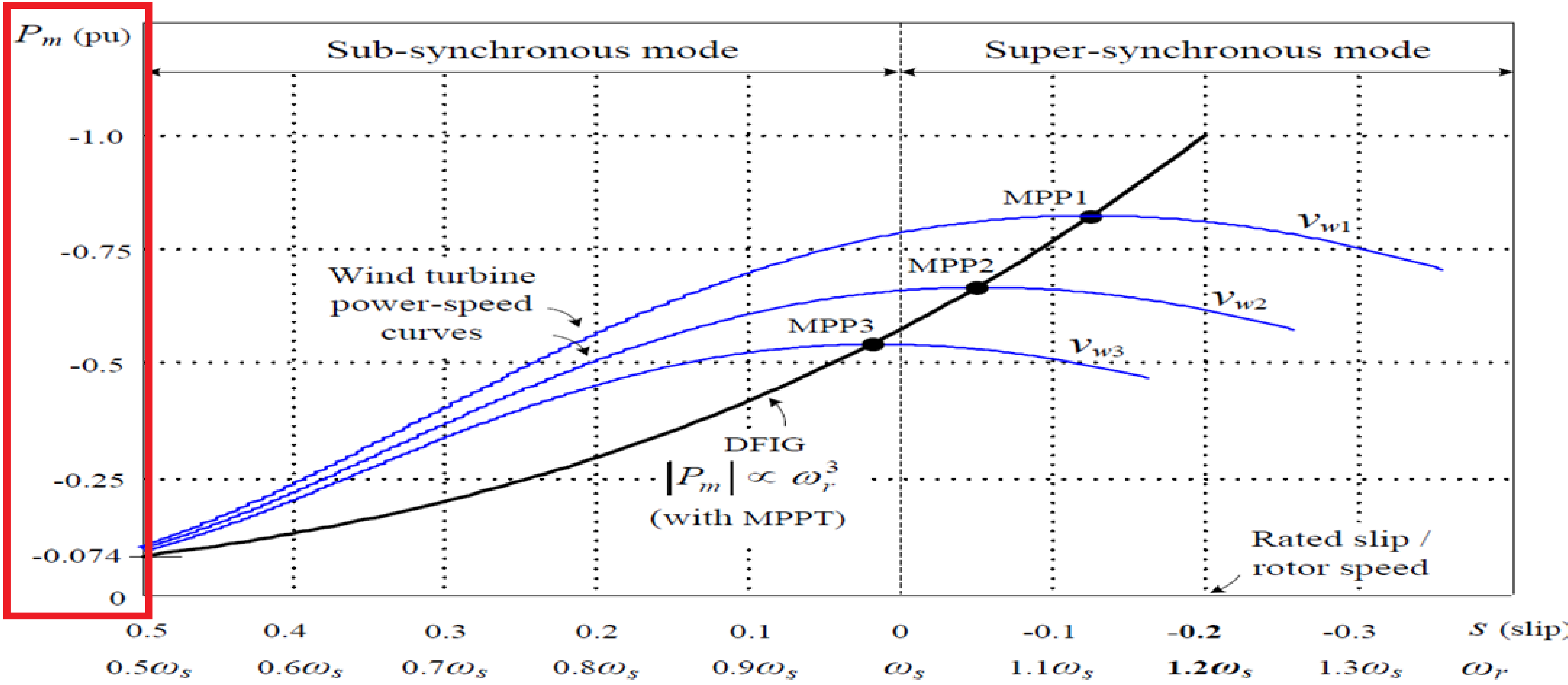


Q.Why *Pm* is –ve?

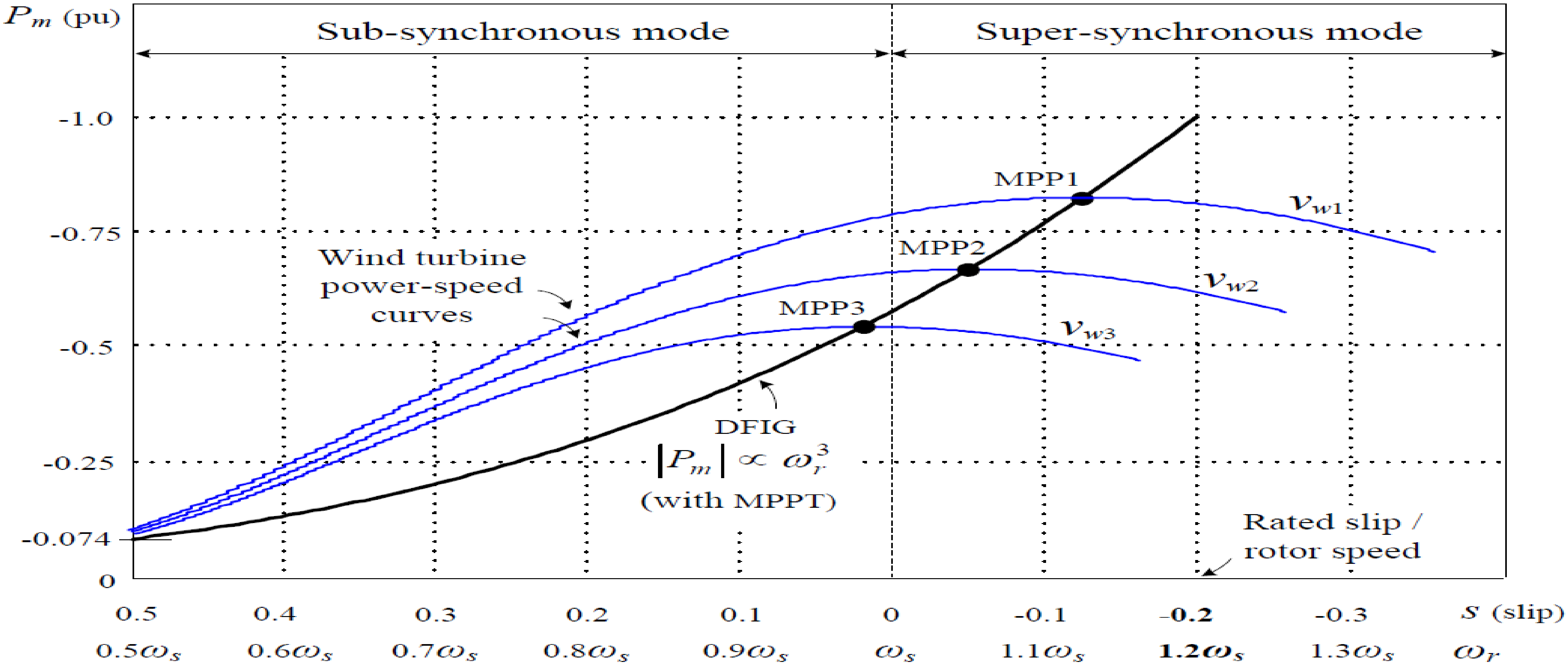


P_m (pu)
Sub-synchronous mode
Super-synchronous mode
-1.0
-0.75
-0.5
-0.25
-0.074
0
MPP1
MPP2
MPP3
v_{w1}
v_{w2}
v_{w3}
Wind turbine
power-speed
curves
DFIG
$|P_m| \propto \omega_r^3$
(with MPPT)
Rated slip /
rotor speed
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
s (slip)
$0.5\omega_s$
$0.6\omega_s$
$0.7\omega_s$
$0.8\omega_s$
$0.9\omega_s$
ω_s
$1.1\omega_s$
$1.2\omega_s$
$1.3\omega_s$
ω_r

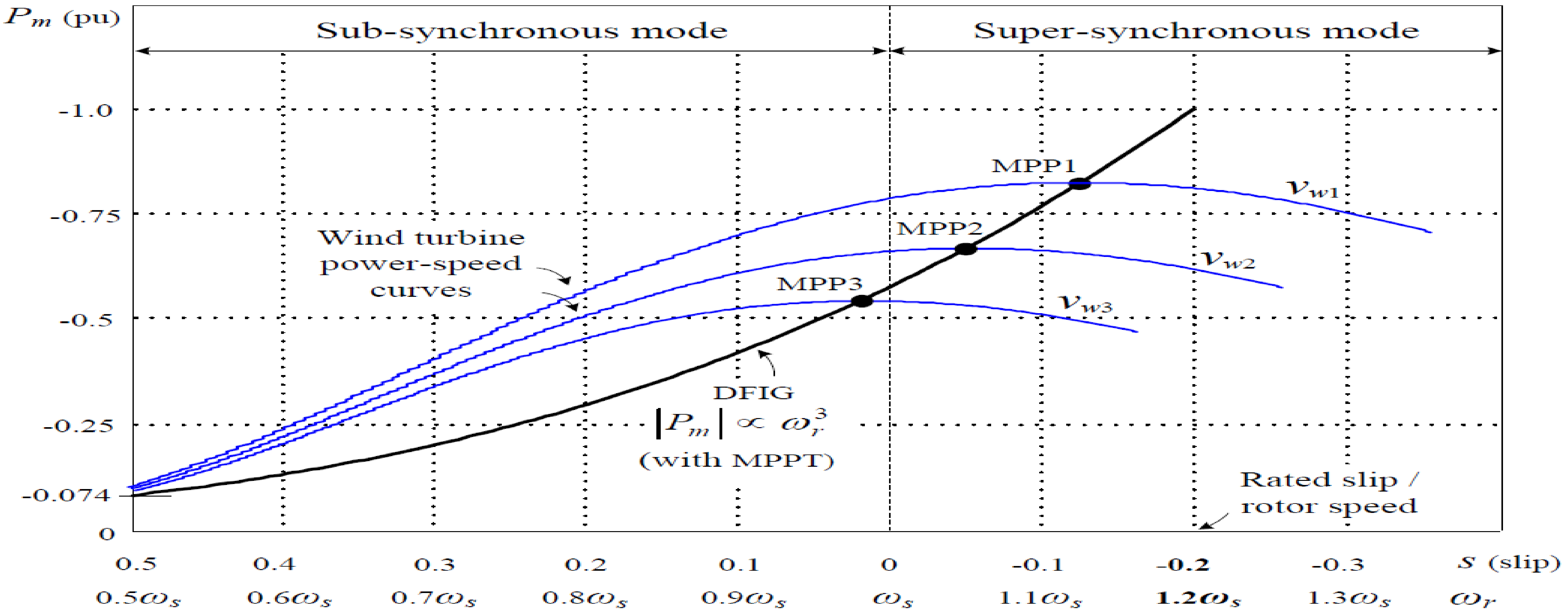
DFIG is in generating mode so *Pm=-ve*



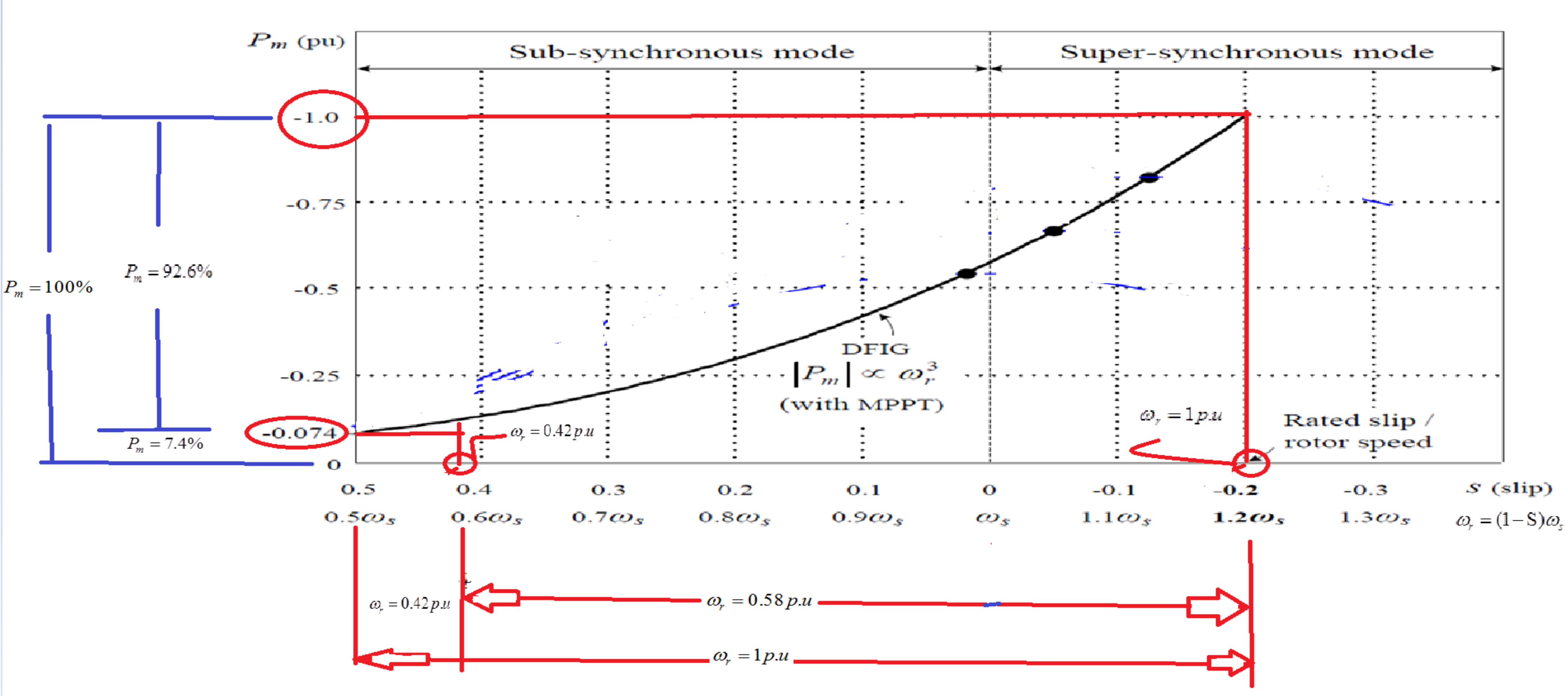
As rotor speed of DFIG is adjustable so Maximum Power Point Tracking (MPPT) scheme can be implemented to harvest maximum available power from wind turbine.



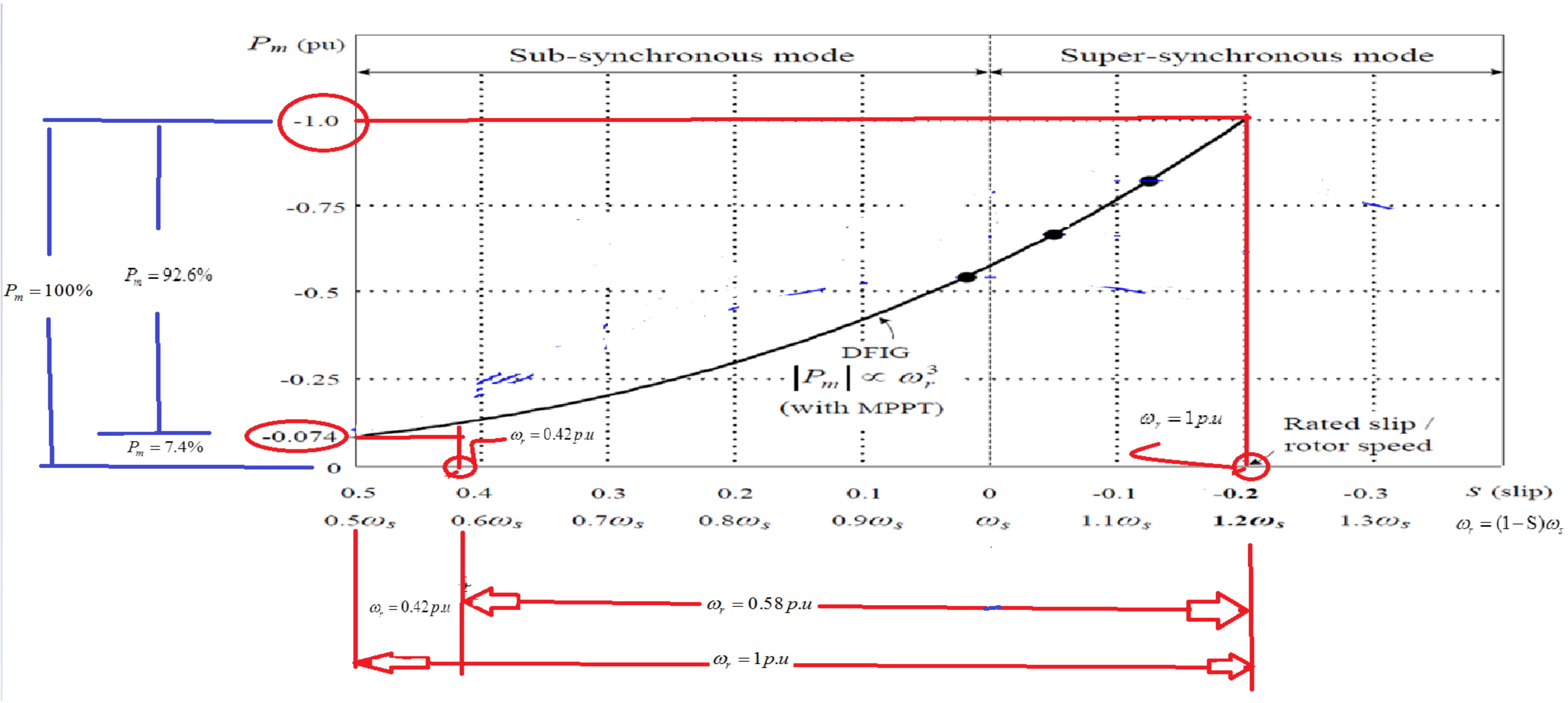
At Maximum Power Point (MPP):**generator's mechanical power from shaft *Pm* is proportional to cube of rotor speed *ωr*** $\cdot |P_m| \propto \omega_r^3$ **.**



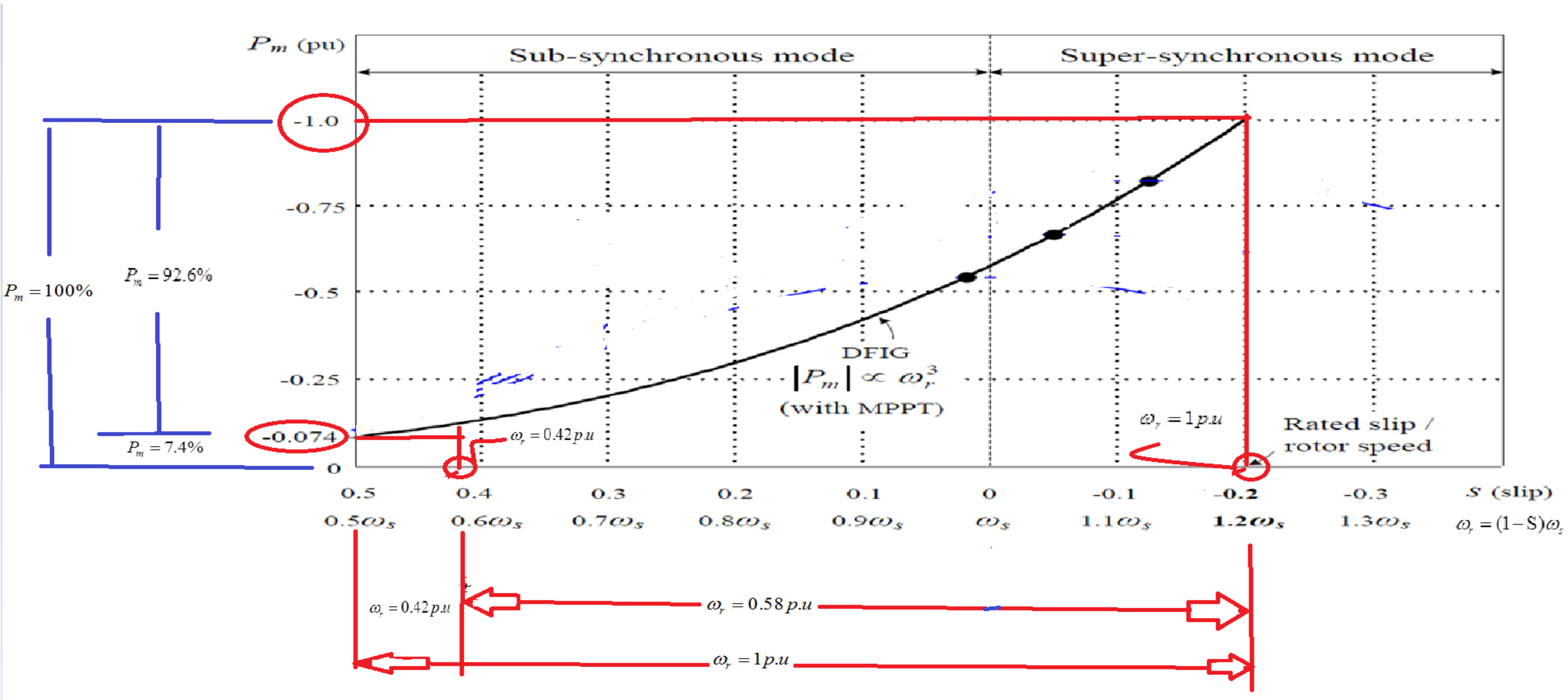
Range of Rotor speed =0.5ωs to 1.2ωs, which corresponds to about 58% of full speed range (0 to 1.2ωs). This speed range is normally sufficient for a wind energy system



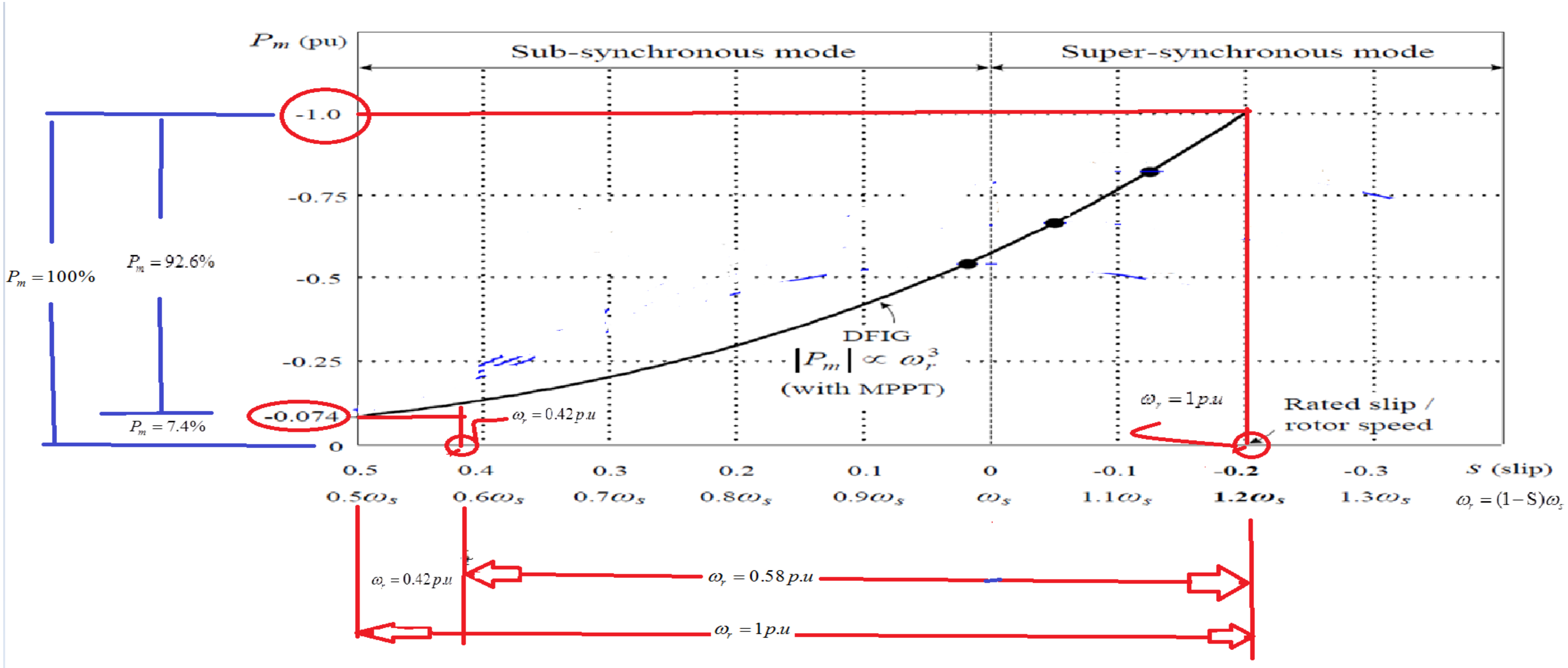
Why? This speed range is normally sufficient for a wind energy system?



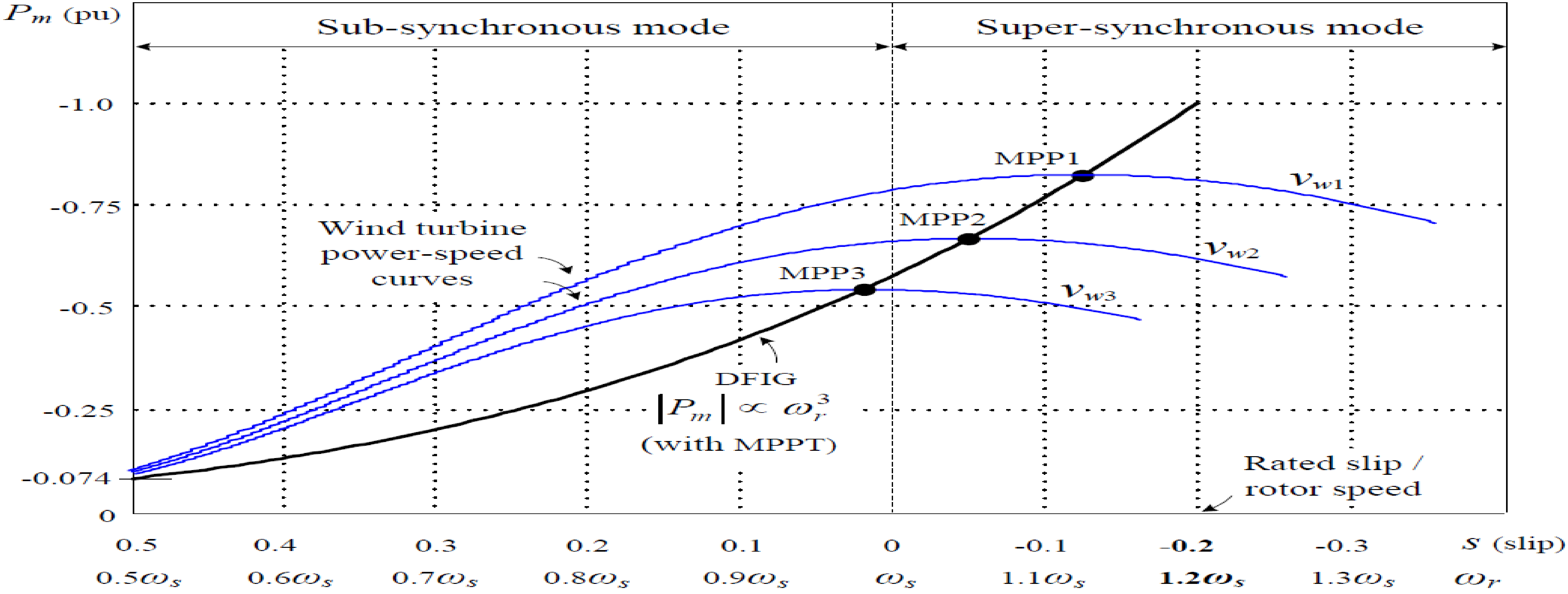
Since power generated at 42%(100%-58%=42%) of rated speed = 0.074 pu ($0.074=0.42^3$), only 7.4% of rated power.



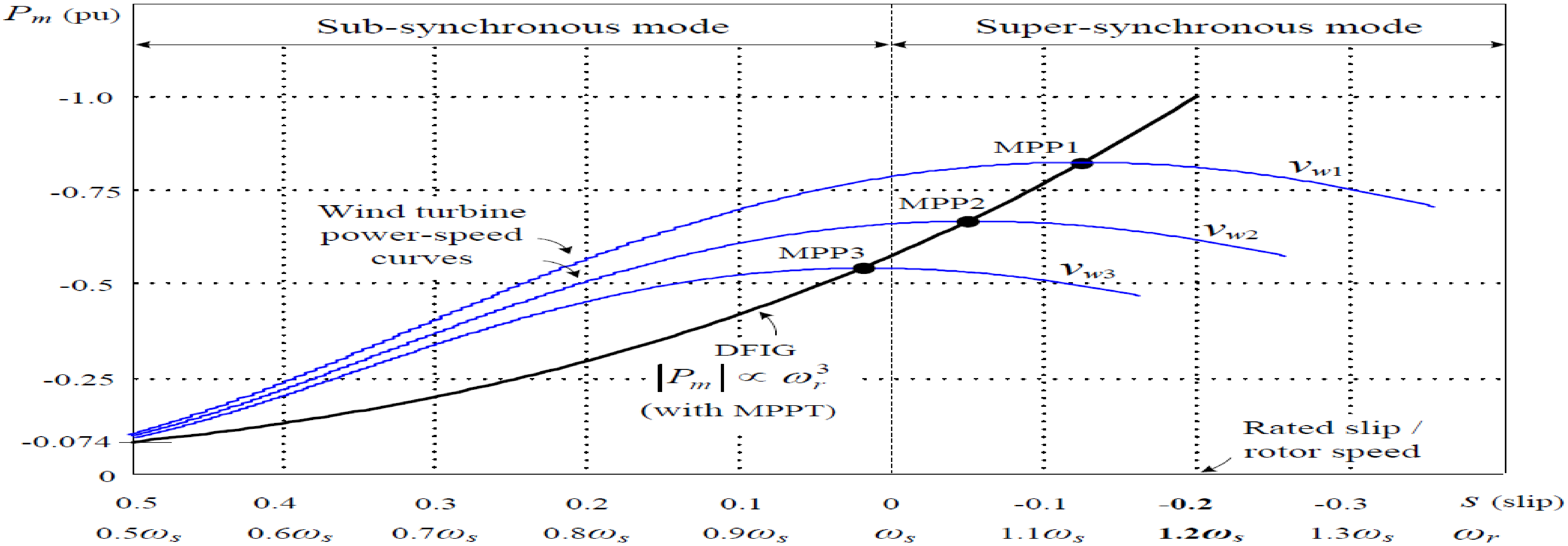
Rated slip at which rated power (1 pu) is generated at -0.2, which represents rated steady-state operating point of system.



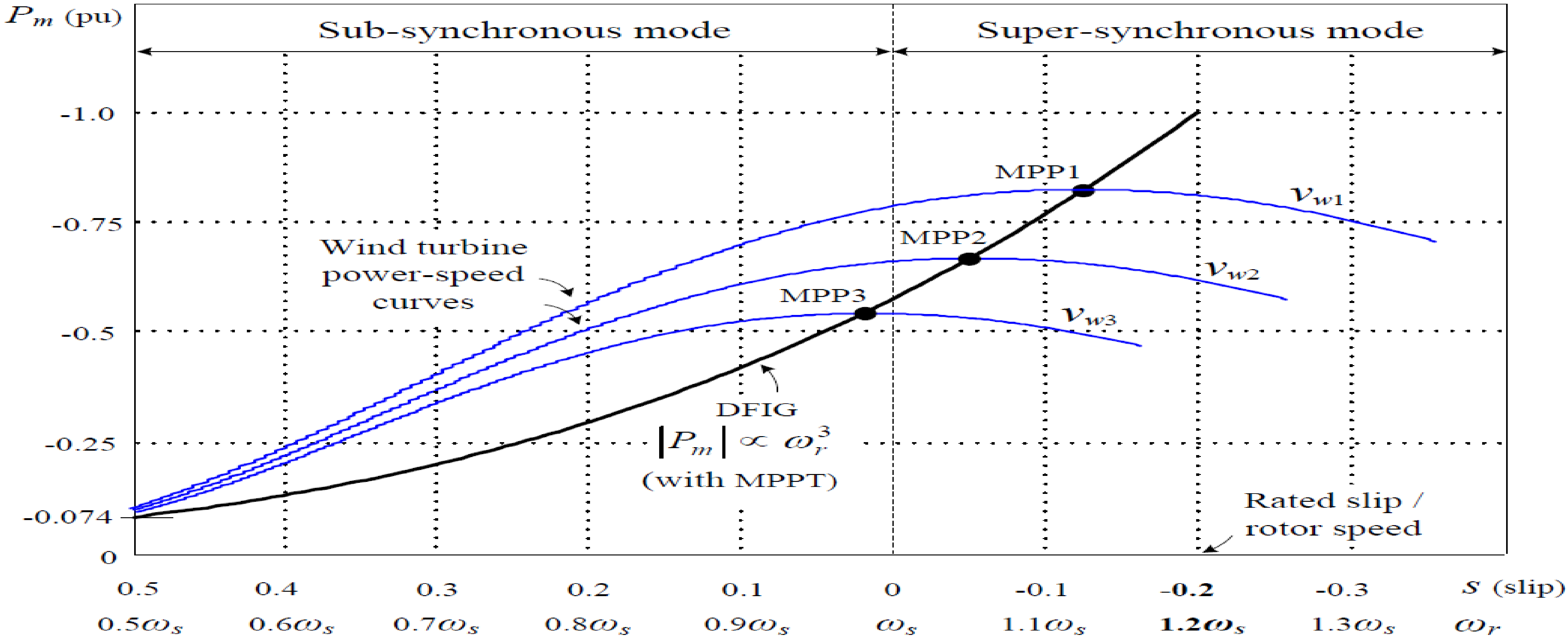
DFIG may operate up to a slip of -0.3 pu (30% above synchronous speed ωs) so power converters in rotor circuit should be designed to handle about 30% of rated stator power.



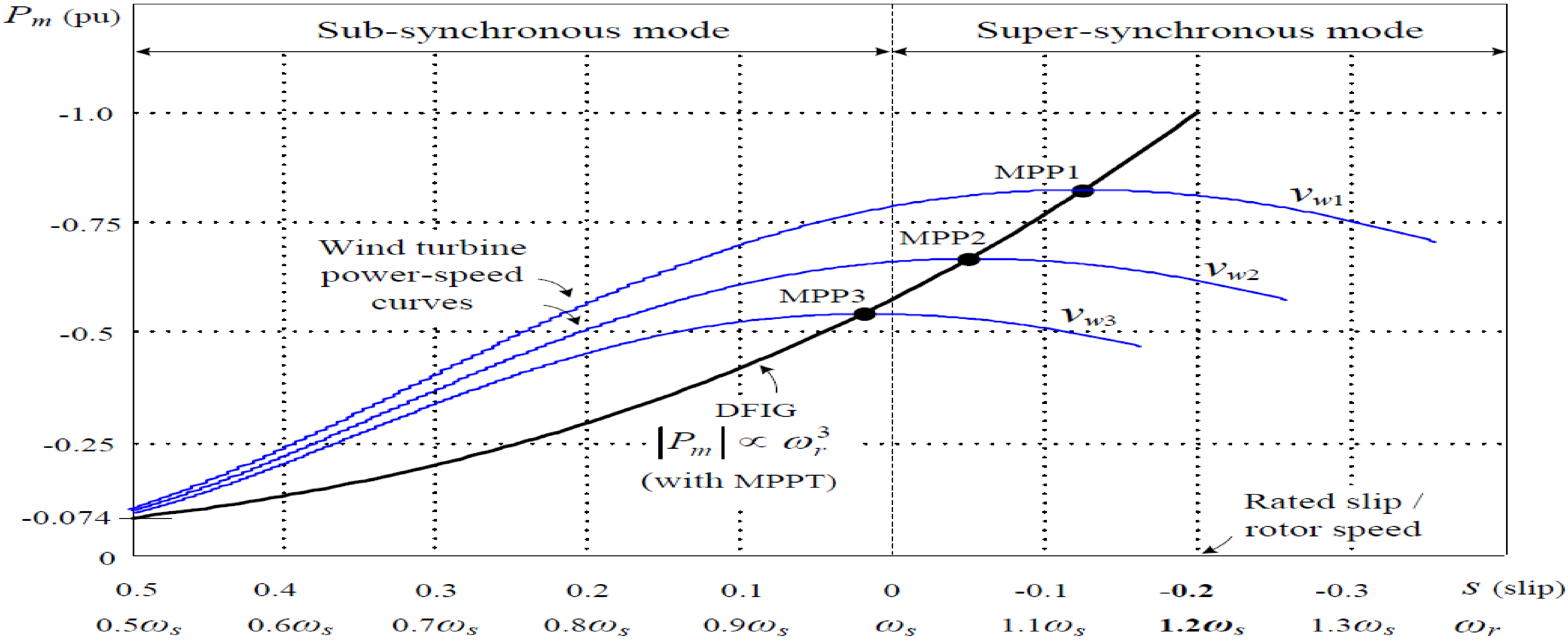
Depending on rotor speed, there are 2 modes of operation in a DFIG based WECS : 1) Super-synchronous mode, where generator operates above synchronous speed *ωs*



2) Sub-synchronous mode, in which generator operates below synchronous speed



Slip is -ve in super-synchronous mode & becomes +ve in sub-synchronous mode.

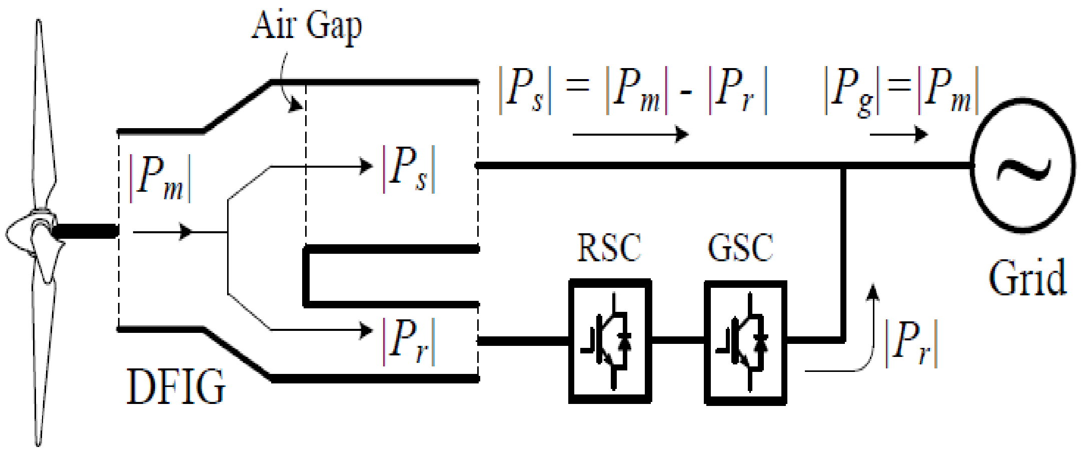


Power flow in a DFIG wind energy system super-synchronous mode vs sub-synchronous mode

Depending on whether slip is +ve or -ve, **rotor circuit** can receive or deliver power from or to grid.

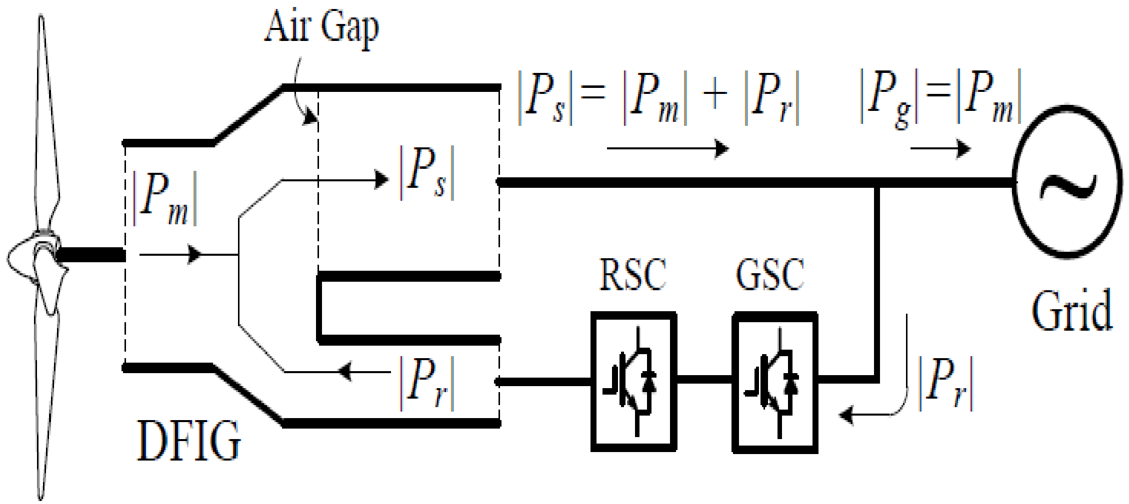
SUPER-SYNCHRONOUS MODE

- |Pm| is delivered to grid through both stator & rotor circuits.
- |*Ps*| is delivered to grid directly.
- |Pr| is transferred to grid by power converters in rotor circuit.
- |*Ps*| = |*Pm*|-|*Pr*|
- |*Pm*| is higher than that in sub-synchronous mode.



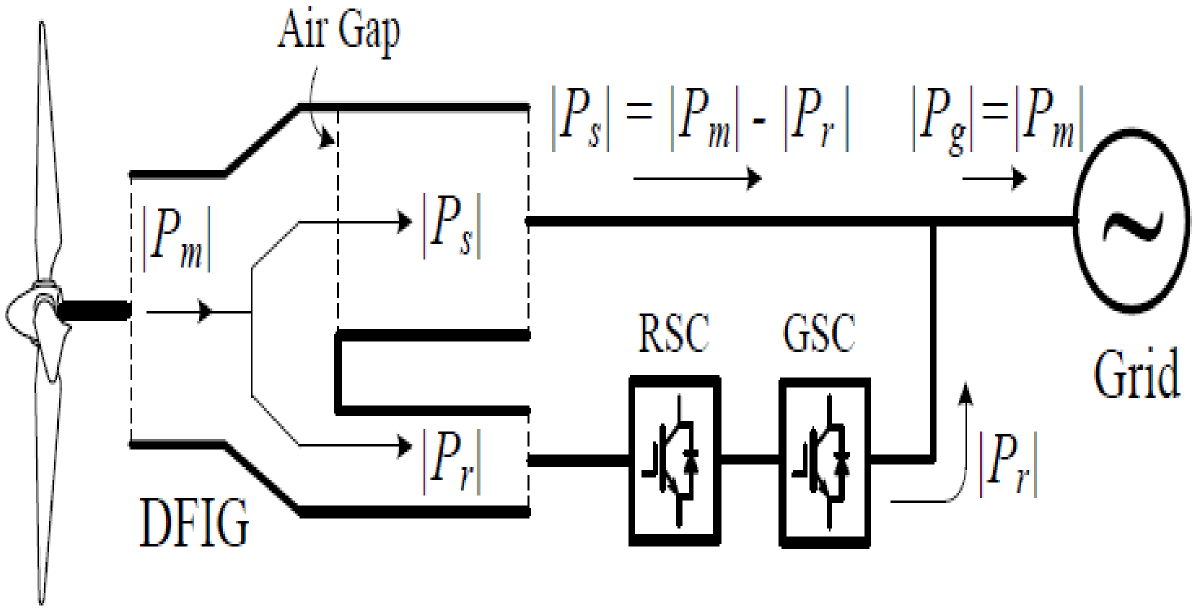
SUB-SYNCHRONOUS MODE

- Both |*Pm*| & |*Pr*| are delivered to grid through stator.
- |*Pr*| is received from grid.
- |*Ps*| = |*Pm*| +|*Pr*|
- |*Pm*| is lower than that in super-synchronous mode.



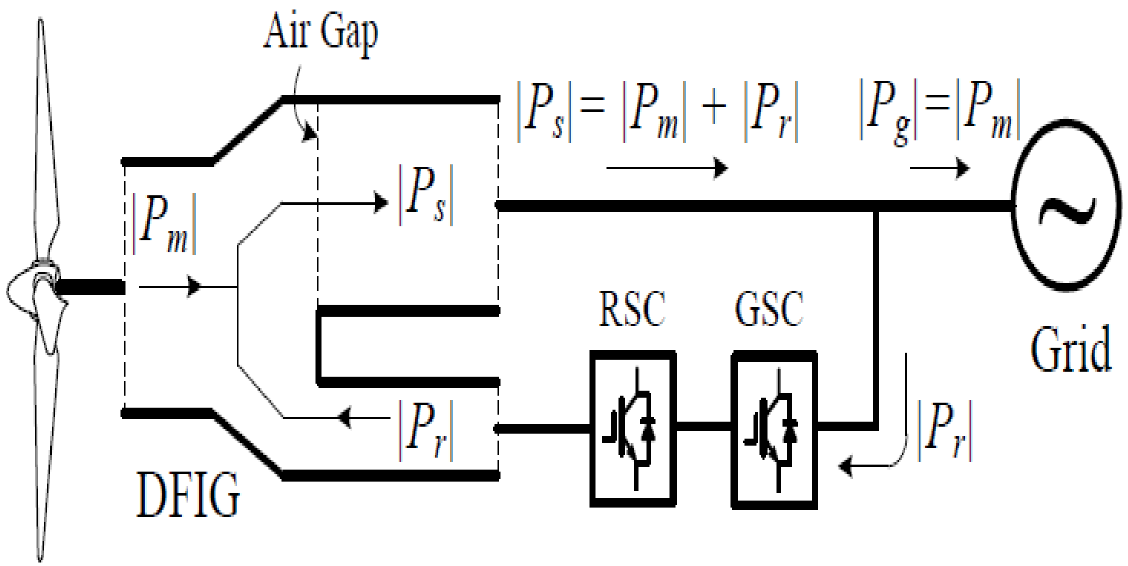
Super-synchronous mode

- Neglecting losses in generator & converters, power delivered to grid |*Pg*| is equal to mechanical power |*Pm*| of generator i.e |*Pg*| = |*Pm*|



Sub-synchronous mode

- Neglecting losses in generator & converters, power delivered to grid |*Pg*| is equal to mechanical power |*Pm*| of generator i.e |*Pg*| = |*Pm*|



Since DFIG generates less power when operating in sub-synchronous mode,

- Power rating for converter is determined by rated or maximum slip in super-synchronous mode, where converters handle highest rotor power. e.g
- Mximum slip for a DFIG during transients caused by gusts of wind is |-0.3| & power to be processed by converters is approximately 0.3 of maximum stator power.