

Wind Farm Balance of Plant

A Practical Guide

Francesco Miceli

windfarmbop.com

Wind Farm Balance of Plant — A Practical Guide

© 2026 Francesco Miceli. All rights reserved.

No part of this publication may be reproduced, distributed, or transmitted
in any form or by any means without the prior written permission of the author.

First edition - April 2026

Table of Contents

Table of Contents.....	3
Important Notice	7
Chapter 1 — What is Balance of Plant?.....	10
The components of Balance of Plant.....	11
How a wind farm project comes together	13
Contract structures	15
The economics of BoP	16
BoP vs BoS — a note on terminology.....	17
What is next	17
Key references	18
Chapter 2 — Wind Resource and Site Assessment	20
Measuring the wind	20
Analysing the data.....	21
Long-term correlation	22
IEC wind classes and turbine suitability.....	23
Energy assessment.....	23
The Wind Farm Assessment report.....	24
What the BoP engineer needs from the WFA.....	26
Software tools	26
Micrositing.....	26
Key references	27
Chapter 3 — Geotechnical Investigation.....	29
What the investigation needs to cover	29
The phased approach	30
Field tests: boreholes, SPT, CPT, and trial pits	31
Laboratory tests	35
Geophysical methods: MASW, seismic refraction, and GPR.....	36
Special challenges.....	37
The geotechnical report.....	39
How geotechnical data drives design	40
Real-world example: reading a geotechnical report from Guatemala	42

Key references	45
Chapter 4 — Access Roads.....	47
Why wind farm roads are not highways.....	48
Road cross-section and geometry	49
CBR, gravel thickness, and materials	49
Gradients, bends, and transport constraints.....	51
The Road Survey	54
Drainage — the silent killer.....	55
Soil stabilization for difficult ground	57
Quality control and testing.....	62
Design software and optimization	63
Common design errors	64
Key references	65
Chapter 5 — Crane Pads and Hardstands.....	67
Shape and dimensions	68
Technical requirements	71
Materials and construction	72
The plate bearing test	74
Crane types and their specific requirements.....	75
Optimization	76
Common design errors	77
Installation compounds.....	78
Key references	79
Chapter 6 — Foundations	81
Foundation types	81
Design principles	84
The grouting connection.....	85
Construction sequence — embedded cylinder	86
Construction sequence — anchor cage	87
Common problems	89
Alternative foundation concepts	91
Key references	92
Chapter 7 — Towers	94
Tower types	94

Stiff, soft, or soft-soft?	97
The transport challenge	98
Tower erection and the BoP interface.....	100
Alternative tower concepts.....	101
The tower's impact on BoP cost.....	103
Key references	104
Chapter 8 — Cranes & Special Transport	106
Types of cranes	106
Transport: getting the pieces to site.....	108
The crane pad.....	111
Blade installation methods	113
Crane mobilisation and movement.....	114
Tower cranes: an emerging alternative	116
The BoP cost impact of cranes.....	117
Key references	117
Chapter 9 — Collector System: Cables, Trenches & Fibre.....	120
Medium voltage cables	120
Cable trenches.....	122
Earthing system.....	126
Optical fibre.....	127
Electrical losses	127
The cable-foundation interface	128
Cost drivers and practical considerations.....	129
Key references	130
Chapter 10 — Substation & Grid Connection.....	132
The main components	132
The power transformer	133
Busbar configuration: single vs double.....	135
Clearances: why dimensions matter	136
Substation earthing (IEEE 80).....	136
Protection system.....	138
SCADA and communication	139
Grid connection options.....	139
Switching centres.....	140

Grid codes: the rules of the game	142
Cost structure.....	142
Key references	143

Important Notice

This book is based on the personal experience and professional opinions of the author, accumulated over more than fifteen years of work in the wind energy industry. It is intended as a practical guide and educational resource for engineers, project managers, and other professionals involved in wind farm Balance of Plant.

However, every wind farm project is unique. The specific conditions of each site — its geology, climate, topography, regulatory environment, contractual framework, and dozens of other variables — make it impossible to provide universal solutions that apply without modification to every situation. What worked on a project in Jordan may not work in Italy. What was acceptable under one set of design codes may not comply with another.

The information, recommendations, data, and examples presented in this book should not be applied blindly to any project. They are starting points for engineering judgement, not substitutes for it. Every number, every design choice, and every construction method described here must be verified, adapted, and validated by qualified professionals in the context of the specific project, the applicable codes and standards, the contractual requirements, and the local conditions.

In particular:

- Design values and calculations presented as examples are illustrative. They must not be used directly in any project without independent verification by a qualified structural, geotechnical, or electrical engineer.
- References to specific products, manufacturers, or technical solutions do not constitute endorsements. The wind energy industry evolves rapidly, and products available at the time of writing may have been modified, discontinued, or superseded.
- Construction methods and sequences described here reflect the author's experience with specific projects and turbine models. Other manufacturers and contractors may use different approaches that are equally valid.
- Regulatory requirements vary by country, region, and municipality. The codes and standards cited in this book (IEC, Eurocode, DNV, etc.) may not apply in your jurisdiction, or may have been updated since publication.
- Cost figures and economic data are indicative and based on the author's experience at a specific point in time. They should be used only for order-of-magnitude estimates, never for project budgeting or investment decisions.
- Photographs and diagrams are included for educational purposes. Some have been cropped, annotated, or simplified for clarity and may not represent the complete engineering detail of the original element.

The author and publisher accept no liability for any loss, damage, injury, or consequence of any kind arising from the use or misuse of the information contained in this book.

Engineering is a profession that carries responsibility. The reader is expected to exercise that responsibility fully.

If something in this book does not look right for your project, it probably is not. Trust your engineering judgement. Ask questions. Verify independently. And when in doubt, consult a specialist.

That said — I hope this book helps you avoid at least some of the mistakes I have made along the way, and gives you a solid starting point for the fascinating work of building wind farms.

Francesco Miceli

April 2026

Chapter 1

What is Balance of Plant?

Chapter 1 — What is Balance of Plant?

If you are reading this book, you probably already have some connection to the wind energy industry. Perhaps you are a civil engineer starting your first wind farm project. Perhaps you are a project manager who has been handling solar plants and is now moving into wind. Or perhaps you are an investor trying to understand what exactly you are paying for when someone hands you a line item called "Balance of Plant" that represents 20 to 30% of your total investment.

Whatever brought you here, this chapter will answer a deceptively simple question: what is BoP, and why does it matter?

BoP is an English acronym that stands for Balance of Plant. In the wind farm sector, it means everything but the wind turbines. The roads that bring the components to the site. The concrete foundations that anchor each turbine to the ground for 30 years or more. The underground cables that collect the electricity from every turbine and carry it to a substation. The substation itself, which steps up the voltage for transmission to the grid. And the transmission line — overhead or underground — that connects the wind farm to the wider electrical network.

It sounds like supporting infrastructure. And that is exactly how sometimes it is treated — as an afterthought, something to sort out once the turbine supply contract was signed. But the economics of wind energy have changed dramatically. Turbine prices have been falling for decades, driven by intense competition and continuous technological improvement. BoP costs, on the other hand, have not followed the same downward curve. The concrete, steel, aggregate, copper, and labour that make up the Balance of Plant are largely commodity inputs, and their prices are linked to global markets that do not particularly care about the wind industry's desire for lower cost of energy.

In some projects I have worked on, the BoP share has exceeded 30% of the total capital expenditure. At that level, an expensive BoP can make or kill a deal. Getting it right is no longer optional — it is essential for the economic viability of the project.



Figure 1.1 — A vintage wind turbine up close. The turbine is the visible part of a wind farm, but everything that supports it — from foundation to grid connection — is the Balance of Plant.

The components of Balance of Plant

BoP divides naturally into two main activities: Civil Works and Electrical Works. This division is not just a matter of engineering convenience — it reflects how the work is usually organised, contracted, and managed. In most projects, civil works and electrical works are handled by different subcontractors with different skill sets, different equipment, and (frequently) different objectives and priorities.

Civil Works

Foundations are often the most critical civil works element. Usually, each turbine sits on a reinforced concrete foundation — typically a gravity foundation for onshore wind farms —

designed to resist the enormous overturning moments generated by the wind acting on the rotor at heights of 80 to 150 meters. A typical foundation uses 300 to 500+ cubic meters of concrete and 30 to 40+ tonnes of reinforcing steel. The connection between the foundation and the tower is made through an embedded steel element — either an embedded cylinder (the older system) or an anchor cage (the more modern approach). Foundation design is a discipline in itself, and we will dedicate an entire chapter to it later in the book.

Access roads and crane pads make up the second major civil works package. Every turbine needs a road to reach it and a flat, compacted platform where the crane can set up for installation. In flat terrain with good ground, roads are straightforward and relatively cheap. In mountainous terrain with poor subsoil — which is where many of the best wind sites are — roads and crane pads can become the single most expensive item in the BoP budget. I have seen projects where roads alone accounted for 5% of the total wind farm cost, because extensive works were needed not only on site but also on the public road from the port to the wind farm.

Cable trenches are the civil works portion of the collector system — the excavation, backfill, and reinstatement of the trenches that carry the medium voltage cables between turbines and from the last turbine to the substation.

Electrical Works

The collector system (also called the internal grid or inter-array cables) consists of medium voltage cables — typically 20 to 33 kV — connecting all turbines to the substation. The cables are buried in trenches alongside fibre optic cables for the SCADA communication system. The collector system also includes the earthing (grounding) network — a critical safety element that connects all metallic components to earth.

The substation is where the electricity generated by the turbines is collected, stepped up in voltage (from medium to high voltage — typically from 33 kV to 110, 132 or 220 kV), and prepared for export to the grid. A wind farm substation contains power transformers, high voltage switchgear, protection and control systems, SCADA servers, metering, auxiliary services (low voltage supply, UPS, lighting, HVAC) and sometimes reactive power compensation equipment. It is typically housed in a purpose-built building on a dedicated platform.

The transmission line connects the wind farm substation to the point of common coupling (PCC) — the point where the wind farm meets the existing electrical grid. This can be an overhead line, an underground cable, or a combination of both. The distance can range from a few hundred meters (if the wind farm is fortunate enough to be next to an existing substation) to tens of kilometres. In some projects, the cost of the transmission line alone exceeds the cost of all the civil works combined.