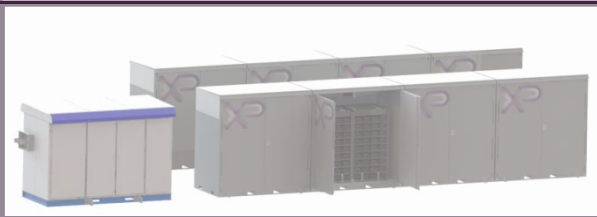




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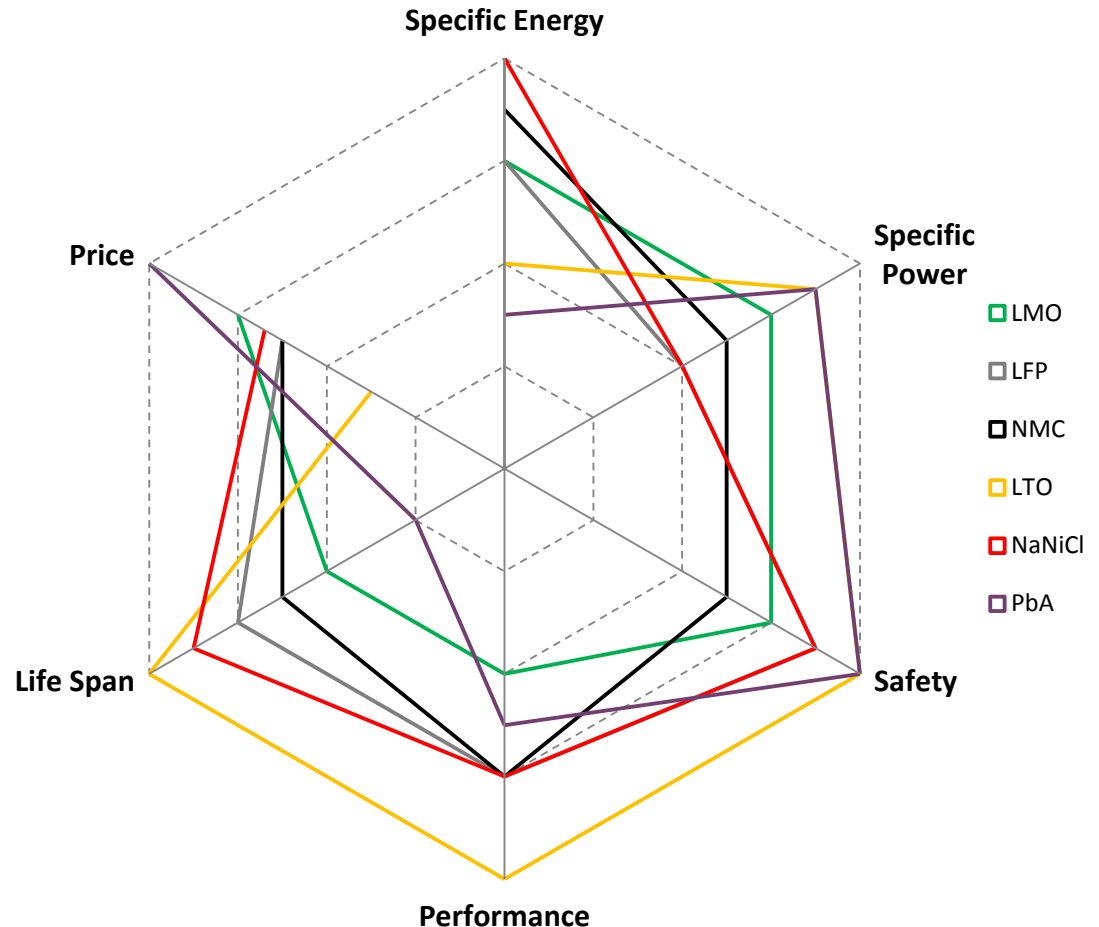


## Battery Energy Storage Systems and their Control

March 2014

# Battery Selection

- To date, no single battery chemistry is perfect
- There are no “good” or “bad” batteries, just different
- Pick the application, then pick the battery technology
- Multiple application system may utilize multiple battery types (i.e. *Hybrid systems*)

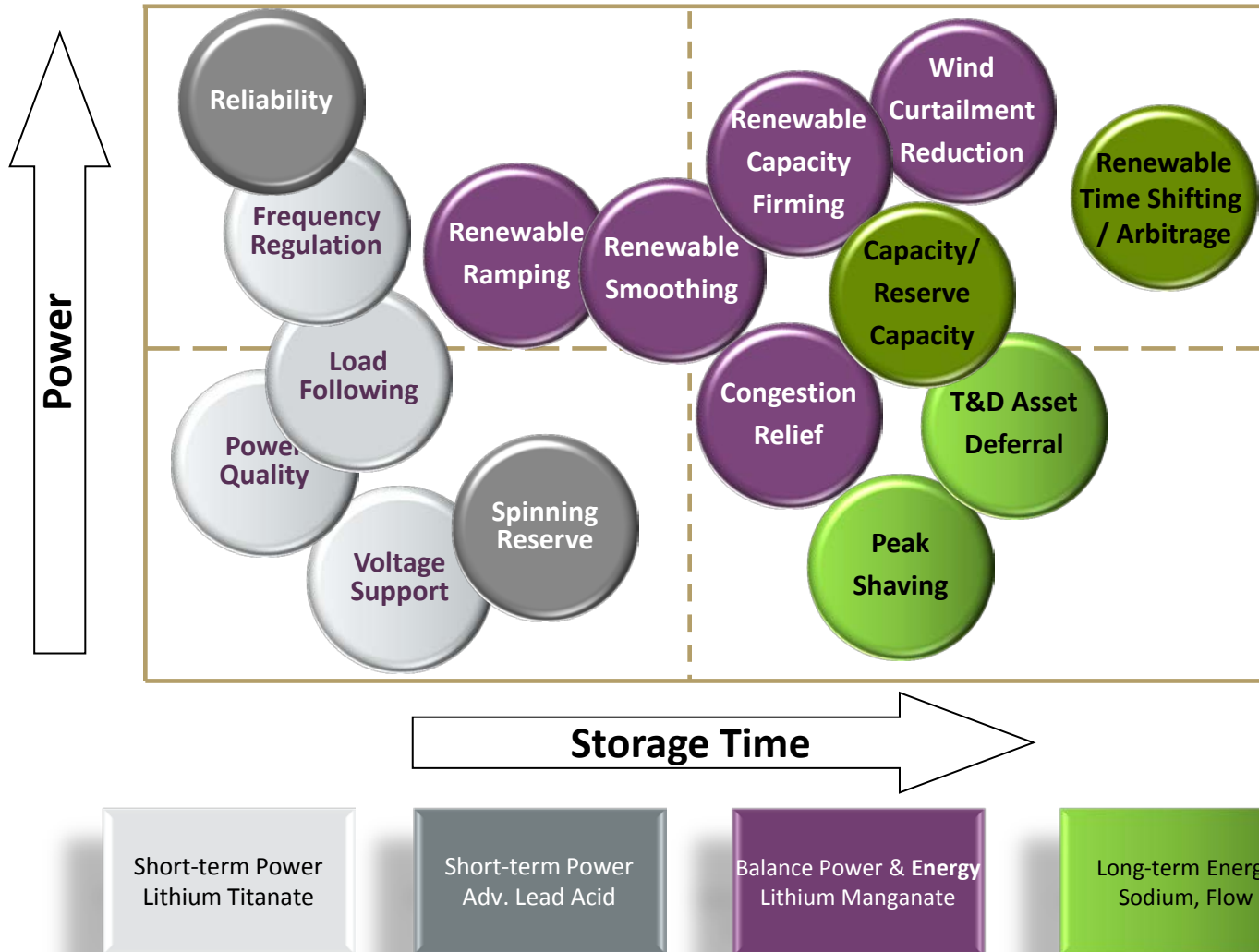


- Every battery will be defined by its key parameters and specifications.
- While there might be hundreds of battery characteristics, there are a handful of important characteristics that define compatibility of the battery to a particular application.
- XP utilizes 20 evaluation criteria (10 technical, 10 commercial) with the following being key metrics:
  - **Price**
  - **Safety**
  - **C-Rate**
  - **Cycle Life (energy throughput)**

# Battery Types for ESS

Technology	Type	Price	Cycle Life	C-Rate	Example Manufacturers
Lead Acid	VRLA (Valve regulated lead acid)	\$	*	**	EnerSys, BSB, Shin Kobe, Exide, East Penn
	Flooded lead acid	\$	*	**	EnerSys, Exide, East Penn
	PbC (Lead carbon)	\$\$	**	**	Axion, Firefly
Lithium Ion	<b>LTO (Lithium titanate)</b>	\$\$\$\$\$\$	*****	***	<b>Toshiba</b> , Microvast, Altar Nano
	<b>LMO (Lithium manganese oxide)</b>	\$\$\$	***	**	<b>Samsung SDI</b> , Sanyo, Hitachi, 4R, Actacell, Panasonic
	NCA (Lithium nickel cobalt aluminum oxide)	\$\$\$\$	**	***	Saft, Panasonic, JCI
	NMC (Lithium nickel manganese cobalt oxide)	\$\$\$\$	***	**	Dow Kokam, EnerDel, LG Chem, Sanyo, SK
	LFP (Lithium iron phosphate)	\$\$\$\$	****	**	CALB, A123, Valence, Saft, BYD Bren-tronics
	LCO (Lithium cobalt oxide)	\$\$\$	*	**	GS Yuasa
Sodium	Na Ion	\$	***	*	Aquion
	NaNiCl <sub>2</sub> (Sodium nickel chloride)	\$\$\$\$	***	*	GE, Fiamm
	NaS (Sodium sulphur)	\$\$\$	***	*	NGK
Flow	ZnBr (Zinc bromine)	?	***	*	Redflow
	ICB (Iron chromium)	?	***	*	EnerVault
	VRB (Vanadium redox)	?	***	*	Prudent Energy

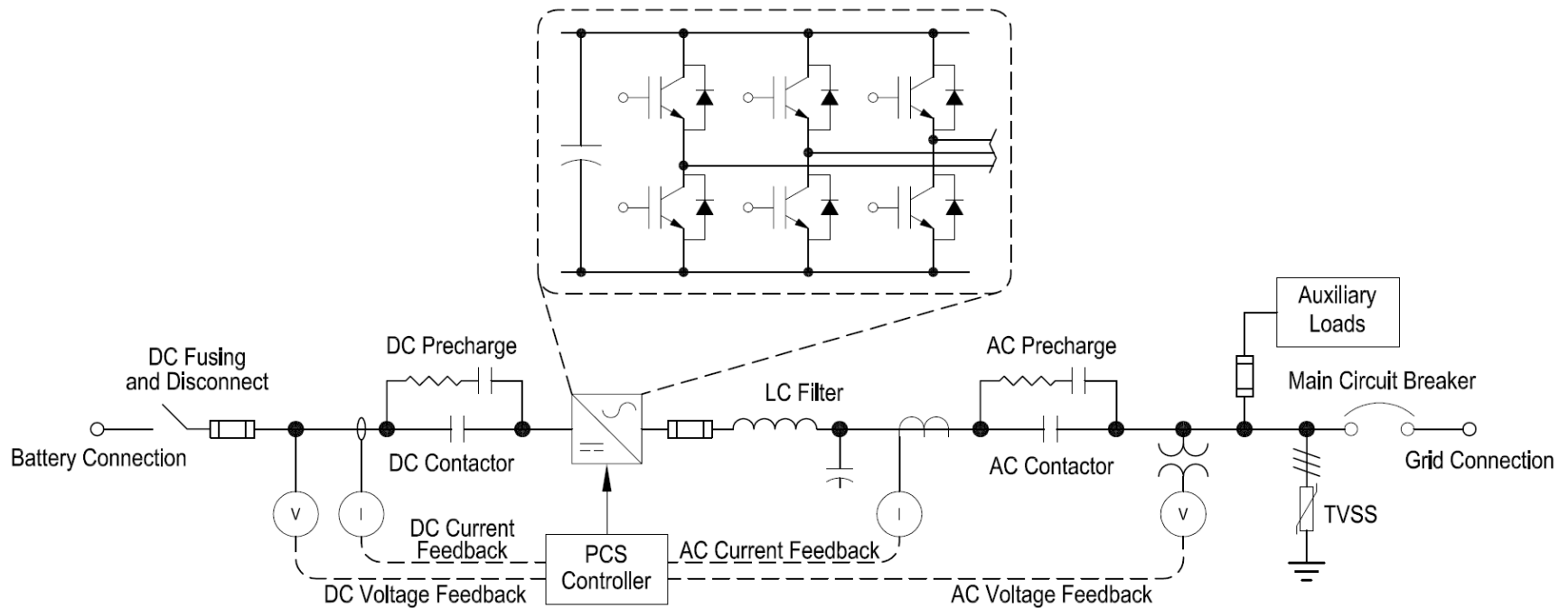
## Multiple Battery Technologies are Required to Meet Today's Diverse Energy Needs



- **PJM Fast Frequency Regulation Service (FRRS)**
  - Power-centric application
    - high power
    - lower energy requirement
  - Partial state-of-charge operation required
- **LTO (Lithium Titanate Oxide)**

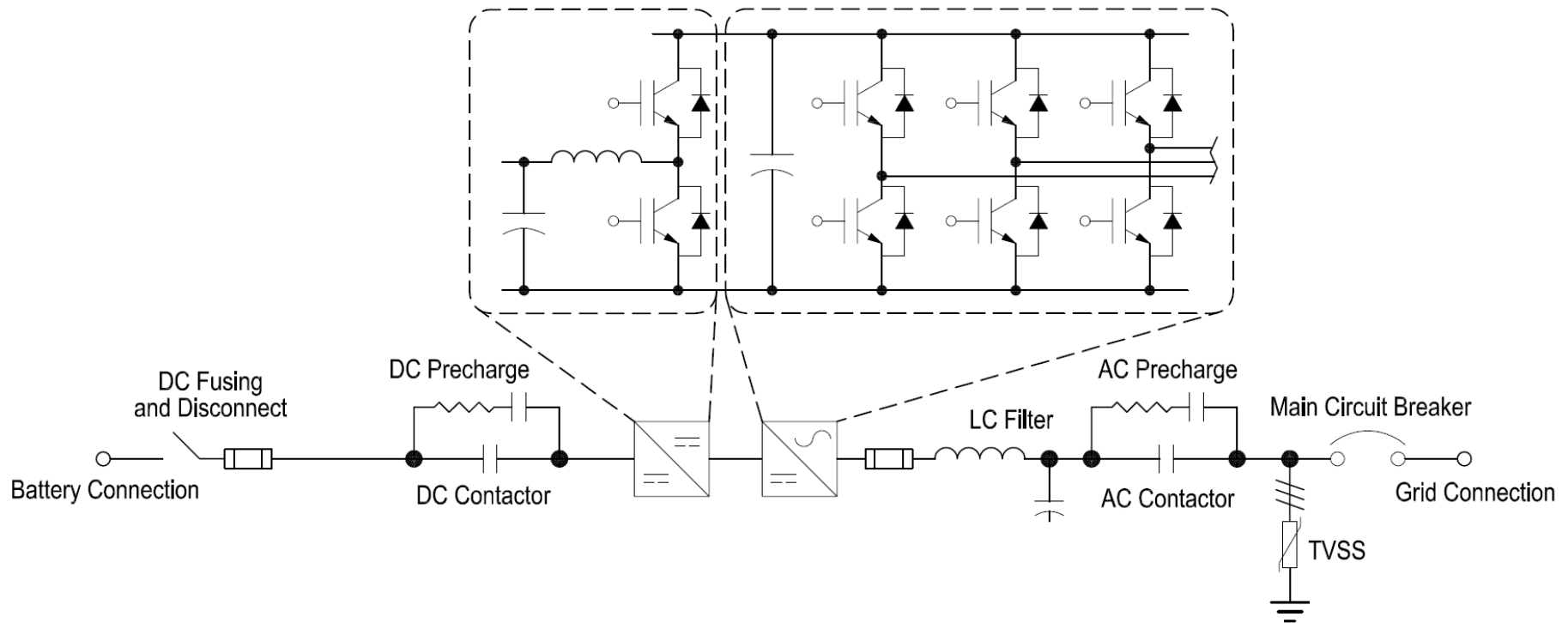
- **High fault energy – protection considerations**
- **Possible wide DC link operating voltage range**
- **Special pre-charge functions**
- **DC link power quality**
- **Robust PLL**
- **Other advanced functionality**

- **Single stage converters**
  - Limited DCV range
  - Minimized hardware costs and losses





- **Multi-stage converters**
  - Increased losses and hardware costs
  - Increased DC voltage range



- **Advanced topologies**

- **Multi-port**

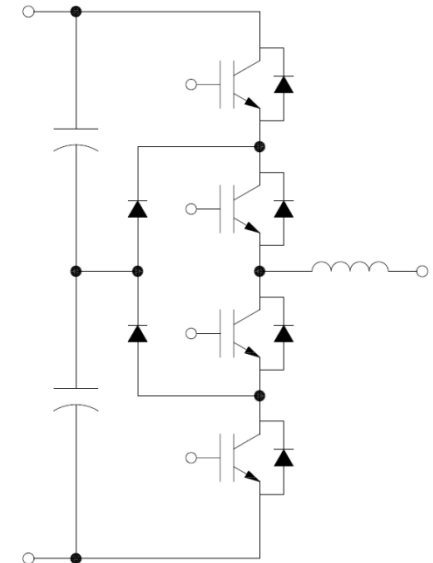
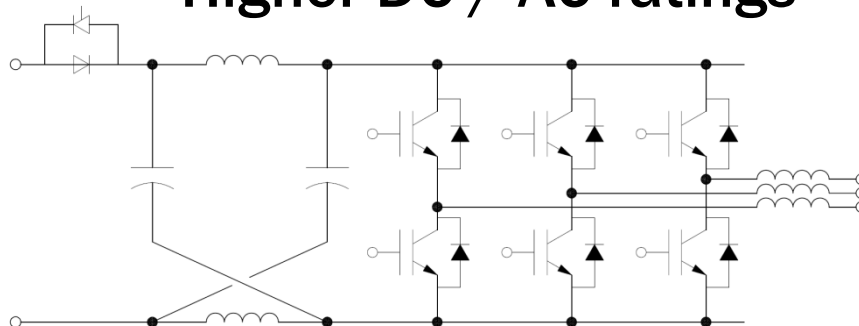
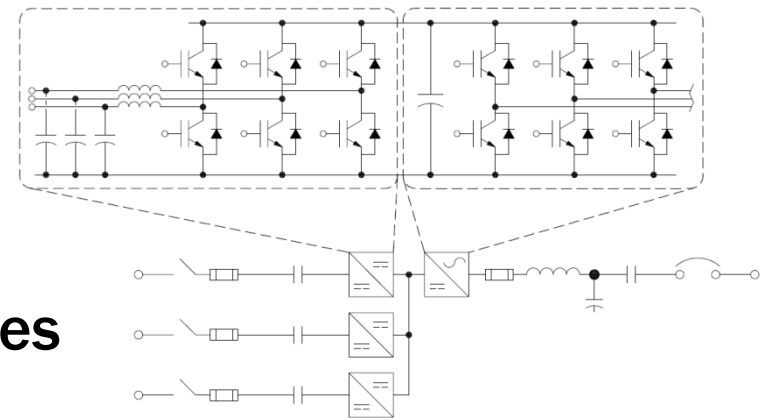
- Support for multiple DC sources

- **Z-inverter**

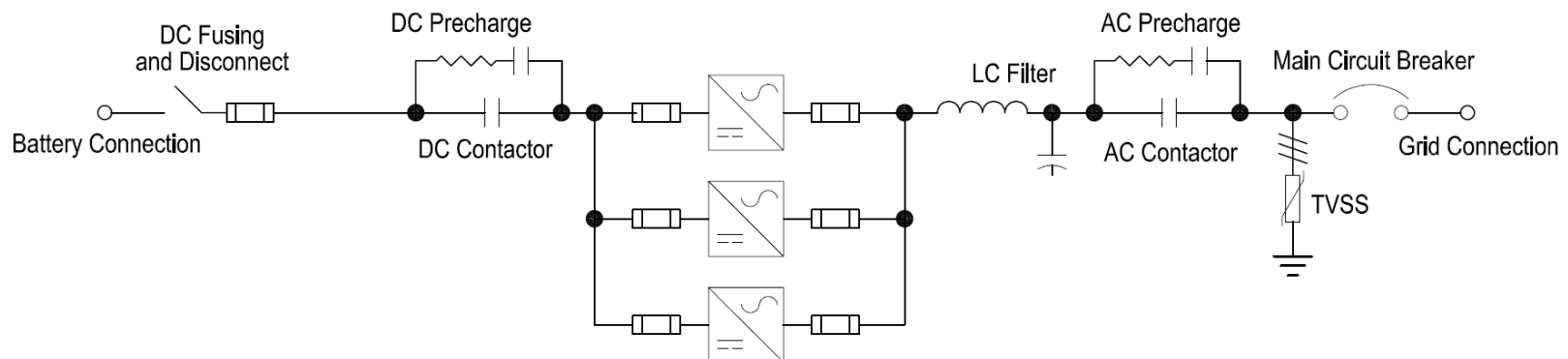
- Functions as both current source and voltage source converter

- **Multi-level inverters**

- Higher DC / AC ratings



- **Multiple modules**
  - Most IGBTs limited to **1,000A**
  - Multiple modules to achieve higher power ratings
  - Some paralleling concerns: cascading failures, resonance, current balancing



- **Functions and applications**
  - Frequency response
  - Remote dispatch
  - Constant DCI / DCV control
  - Low voltage ride-through / VAR injection
  - Frequency ride-through
  - Seamless transfer / islanding mode
  - Independent phase control

- Ramp Rate Control





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