Notes on Selection of Medium Voltage Level for a Microgrid

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Voltage Selection

The idea of medium voltage distribution systems is to reduce losses by using a higher voltage for distribution feeders, then stepping down to a lower voltage for consumption. IEEE 141 (https://standards.ieee.org/findstds/standard/141-1993.html) defines medium voltage as anything between 1 kV and 100 kV that is used in a distribution (rather than transmission) system. Common three-phase wye distribution voltages used in the US are 4.16 / 2.4 kV, 12.47 / 7.2 kV and 22.9 / 13.2 kV. In general, equipment for distribution systems is subdivided into three “classes” – 5 kV, 15 kV and 30 kV classes. In addition, design requirements (such as conductor horizontal spacing, maximum allowable sags, etc.) vary with voltage.

Table 4-1: Standard nominal three-phase system voltages per ANSI C84.1-1989

Voltage Class	Three-wire	Four-wire
Low Voltage		208 Y/120
	240	240/120
	480	480 Y/277
	600	
Medium Voltage	2,400	
	4,160	4,160 Y/2400
	4,800	
	6,900	
		8,320 Y/4800
		12,000 Y/6,930
		12,470 Y/7,200
		13,200 Y/7,620
	13,800	13,800 Y/7,970
		20,780 Y/12,000
		22,860 Y/13,200
	23,000	
		24,940 Y/14,400
	34,500	34,500 Y/19,920
	46,000	
	69,000	
High Voltage	115,000	
	138,000	
	161,000	
	230,000	
Extra-High Voltage	345,000	
	500,000	
	765,000	
Ultra-High Voltage	1,100,000	

The IEC (https://webstore.iec.ch/publication/153) uses a range of 1 kV to 35 kV, with common phase-to-phase voltages including 11 kV, 22 kV and 33 kV.

Table 3 - A,C, three-phase systems having a nominal voltage above 1 kV and not exceeding 35 kV and related equipment*

Series I			Series II	
Highest voltage for equipment kV	Nominal system voltage kV		Highest voltage for equipment kV	Nominal system voltage kV
3,6 1)	3,3 1)	3 1)	4,40 1)	4,16 1)
7,2 1)	6,6 1)	6 1)	–	–
12	11	10	–	–
–	–	–	13,2 2)	12,47 2)
–	–	–	13,97 2)	13,2 2)
–	–	–	14,52 1)	13,8 1)
(17,5)	–	(15)	–	–
24	22	20	–	–
–	–	–	26,4 2)	24,94 2)
36,0 3)	33 3)	–	–	–
–	–	–	36,5 2)	34,5 2)
40,5 3)	–	35 3)	–	–

* These systems are generally three-wire systems unless otherwise indicated, The values indicated are voltages between phases ,
The values indicated in parentheses should be considered as non-preferred values , It is recommended that these values should not be used for new systems to be constructed in future,

NOTE 1 It is recommended that in any one country the ratio between two adjacent nominal voltages should be not less than two,
NOTE 2 In a normal system of Series I, the highest voltage and the lowest voltage do not differ by more than approximately ±10 % from the nominal voltage of the system, In a normal system of Series II, the highest voltage does not differ by more then +5 % and the lowest voltage by more than 10 % from the nominal voltage of the system,

1) These values should not be used for public distribution systems,
2) These systems are generally four-wire systems,
3) The unification of these values is under consideration,

The choice of voltage is dependent on three factors: the electrical load, the distances involved, and national standards. Systems with higher loads over a distribution feeder are likely to use higher voltage to minimize currents and thus wire sizes. Likewise, longer feeders work better with higher voltages since lower current will cause lower voltage drops and thus lower power losses. Finally, it would be impractical to implement large numbers of different voltages on an electric system, so utilities often choose a small number of voltages in order to standardize equipment and designs. As an example, many rural feeders in the United States use 12.47 kV systems to supply loads up to 5-10 MVA.

Microgrid Considerations

Although a microgrid can be considered just a portion of a larger electrical system, rural microgrids often have three defining factors: First, the are electrically isolated from the main electrical grid. Second, they have dedicated generation sources, often in the form of solid state inverters which supply power from batteries and renewable sources such as wind or solar. Finally, the total loads on such systems are often very small – measured in tens of kVA rather than thousands of kVA (1,000 kVA = 1.0 MVA). The individual household loads are often very small as well – as low as one amp at 120V. In addition, the isolation means that the physical area of the community may be small, so distances are limited.

All of these factors argue that a microgrid should use a lower distribution voltage than a large central grid. The IEC 62257 standard for remote hybrid power systems assumes that systems at less than 100 kVA use only low voltage distribution, skipping MV distribution entirely. The only factor that argues for a higher distribution voltage is compliance with a national standard.

As an example, if a microgrid with a maximum load of 50 kW uses a 12.47 / 7.2 kVA three phase wye as its primary distribution voltage, the phase to neutral current would only be two and a half amps per phase at maximum load, and potentially under an amp at low loads. That same system at 22.9 / 13.2 kV would draw only 1.3 amps per phase and under a half amp at minimum load.

The inductance of the wires and transformers used in this type of system becomes a major factor at such low loads and if the wire and magnetics are not chosen properly, inductive circulating currents could cause the system to operate at very low power factors, especially at the generation source. Low power factors will increase current and thus losses, and may cause generators (especially inverters) to have smaller real power output (kW) since the apparent power (kVA) will cause overloads.

It is therefore critical that appropriately sized wires and transformers be used in microgrid distribution systems. For example, use of standard 10kVA pole mount distribution transformers to supply 5-10 houses drawing 120 watts each would contribute to low power factor problems.

"When the big grid meets the little grid …"

If a small rural microgrid is eventually connected to the main grid, there are several options to deal with voltage differences (assuming the main grid uses a higher voltage than the microgrid):

1) The system could be connected via a voltage-matching transformer and appropriate switchgear. This would allow the local distribution system to continue to use the existing insulators, transformers, switchgear, wires and poles.
2) The system could be converted to a higher voltage in preparation for interconnection. This could use potentially use existing wires but would require replacing insulators, switchgear, fusing and transformers (including transformers at the generation site) and changing conductor spacing as well.
3) The existing distribution system could be removed and replaced. This might need to be done anyway if significant load changes were anticipated.
4) One compromise would be to design the poles, wires and insulators in the microgrid to the higher voltage standards and simply run at a lower voltage, using appropriate transformers. This would make the transition much easier since only the transformers would need to be replaced upon connection with the main grid.

Summary

In general, the optimum distribution voltage for a small rural microgrid will be significantly lower than for a large central grid. However, if a higher voltage must be used because of local standards and regulations, it is important to size the transformers and wires appropriately for the lower loads of a microgrid. If this is not done, the circulating current in the system magnetics will cause the system to operate at a low power factor, thus increasing technical losses as well as potentially causing faulty operation of generation equipment and customer loads.