Key considerations for voltage regulating equipment

Voltage regulators vs. on-load tap changers

Overview

Requirements for electrical power transmission and distribution are presenting more challenges every day. Power users need a balanced, stable supply without distortion and interruptions. Increased demand for electricity must be met with an increase in supply. Demands for power must be satisfied without reducing the quality of the supply. The challenges faced are not only driven by large industrial customers, but also from consumers; the needs of each influences the other.

An important component of power quality is a consistent voltage within a specified range. Demand-side management and distribution automation look to utilize existing system resources more efficiently. Paybacks from lower system losses and deferred use of costly peak demand electricity justify purchases of new voltage regulating equipment. Modular designs are favored, using products optimized for their function, with future benefits in ease of repair and improved availability when replacement is needed. These conditions are just some of the factors in the purchase decision process.

Key considerations for voltage regulating equipment

There are four factors to consider when purchasing new voltage regulating equipment.

The factors are:

- Phase balance requirements
- Expected utilization level of equipment
- Ease of use of equipment
- Future maintenance schedules and anticipated repair rate

The voltage supplied by the transmission system may not be balanced because of limited phase transpositions in the transmission lines. Power transformers and feeders impose their own impedance, and the amount of voltage drop depends on the loads and, consequently, the currents that flow through them. There are choices to be made in how to regulate voltage in the substation; some of these choices can require significant capital expenditures.

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Modular equipment

Even in a world of ongoing maintenance and occasional system or component failures, the objectives of minimizing outage time and limiting equipment failures can be realized. The use of per-phase modular equipment provides benefits such as improved equipment availability, equipment optimized to the intended function and reduced engineering design development time. Modular equipment also offers the flexibility of modeling the phase of each feeder to supply power in an optimized voltage range along the distribution line or to the load center.

Voltage regulators vs. on-load tap changers

As an example, in the purchase of equipment to regulate substation voltage, the following product alternatives may be considered (see Figure 1):

1. Bank of single-phase voltage regulators in conjunction with a Power Transformer without an on-load tap changer (OLTC)
2. Power Transformer with an OLTC

Power transformers with a three-phase ganged OLTC cannot correct for phase voltage imbalance and therefore the imbalance is passed directly into the distribution system without any correction.

When utilizing an OLTC, maintenance and repair of equipment provides other challenges. Since voltage regulation equipment and the power transformer are combined into one unit, the entire package must be removed from service while the work is performed. Equipment problems on one phase invariably affects all phases.

With a single-phase voltage regulator, if one phase goes offline, it can be replaced with another single-phase unit. One spare voltage regulator can roll through all three phases when maintenance is required; the same spare unit functions effectively on any of the three phases. Maintenance can be completed without diminishing service anywhere on the system. Spare equipment may be available from emergency reserves, from another substation or as new, direct from the manufacturer or a nearby distributor.

In systems with long distribution lines, additional single-phase step-voltage regulators are often installed to boost the voltage and keep customers at the end of the line within a desired voltage profile. However, the voltage regulation between an OLTC and the step-voltage regulators downstream can be significantly out of balance due to the line drop caused by the additional single-phase loads extending beyond or in parallel with the three-phase service. This allows parts of the line to benefit from single-phase regulation but often leaves the most heavily loaded portion of the line (closest to the substation) susceptible to imbalance.

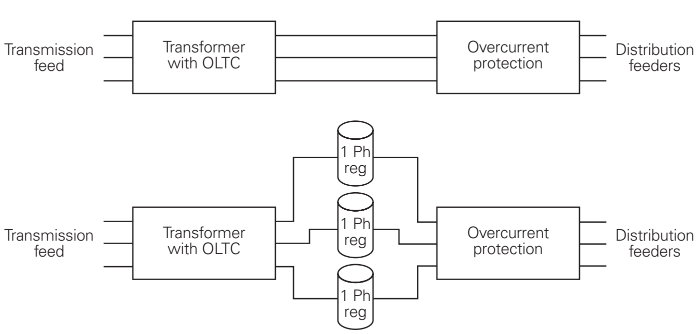

Figure 1. Basic layout differences.

In addition to providing voltage balance for optimal equipment performance, better phase balance improves the effectiveness of energy efficiency programs such as conservation voltage reduction (CVR). Maintaining phase angle balance is handled by the ability to have independent voltage settings within the bank of three independent single-phase step-voltage regulators. While CVR lowers the voltage within acceptable limits, a large phase imbalance limits the effectiveness of CVR programs by limiting the voltage reduction possible, so maximum savings cannot be realized.

Modern voltage regulation

Utilities are moving away from using three-phase ganged OLTCs in their distribution substations, and instead, are now using single-phase, step-voltage regulators to mitigate voltage imbalance issues. The selection of step-voltage regulators over OLTCs for these substation applications has demonstrated the inherent value of being able to control individual phase voltages, as well as the phase angles between them. Having the ability to bypass the step-voltage regulator if it fails, improves system reliability. Engineers are often called upon to provide a contingency plan to transfer load in the event of product failure or scheduled maintenance. Bypass switching provides easy installation and the ability to remove a voltage regulator without "dropping" the entire feeder or bus. Bypassing and the use of spare regulators allows for a simpler load transfer.

Reliability

The recent introduction of vacuum interrupting tap changers with single-phase step-voltage regulators makes it possible for utility operators to provide individual phase regulation without sacrificing the high-reliability seen in vacuum-switched OLTCs. Table 1 below provides the ratings available with Eaton's 2000 Amp EVER-Tap™ tap changer. To the left of the table is the megavolt amperes (MVA) loads that can be regulated by a bank of three voltage regulators. With the latest IEEE/IEC voltage regulator standard, C57.15-2017/60076-21 ED.2, short circuit requirements have been improved to a level matching the power transformer's ability within a substation.

Cost considerations

Table 2 reflects estimated initial and life cycle cost comparisons associated with different types of regulating products applied in a substation. Numbers in this table are based on estimates provided by users and consultants. Actual costs will vary.

When utilizing power transformers with OLTCs, it is usually economically feasible to purchase a maximum MVA rating to cover several loads at the maximum and below. With power transformers without OLTCs, it is economically feasible to size the power transformer and the bank of three regulators specific to the load that needs to be regulated.

Conclusion

Ultimately, the voltage regulating package must support the load it serves. Since the voltage regulating package represents a significant capital investment, practical designs must allow for some degree of load growth. Table 1 shows the amount of capacity available when two stages of fans are included with the higher end of the voltage regulator ratings. It is almost always the case that the cost of such incremental loading capability is less than cost of a voltage regulator with a higher base rating. In some substations, the potential operation configurations need to be considered where paralleled voltage regulating packages are required for handling the entire load if one of the voltage-regulating packages needs maintenance or there is a failure of the power transformer. Inventory costs of maintaining several ratings for various substations must also be considered.

Table 1. Substation step-voltage regulator ratings

Voltage	Tap changer	ONAN				ONAF1				ONAF2				Regulated 3-phase load @ 55 °C rise	Regulated 3-phase load @ 65 °C rise
		55 °C rise		65 °C rise		55 °C rise		65 °C rise		55 °C rise		65 °C rise			
		kVA	Amps	kVA	Amps	kVA	Amps	kVA	Amps	kVA	Amps	kVA	Amps	MVA	MVA
7620/13200Y	QD8	333	438	373	491	443	583	496	652	—	—	—	—	10/12.5	11.2/14
	QD8	416	548	466	614	553	729	620	816	—	—	—	—	12.5/16.7	14/18.6
	QD8	500	656	509	668	—	—	—	—	—	—	—	—	15/15.3	—
	QD8	667	875	—	—	—	—	—	—	—	—	—	—	20	—
	QD8	667	875	747	980	887	1164	994	1303	—	—	—	—	20/26.7	22.4/29.9
	EVER-Tap	667	875	747	980	887	1164	994	1303	1112	1458	1245	1633	20/26.7/33.3	22.4/29.9/37.3
	QD8	833	1093	933	1224	1108	1454	1241	1628	—	—	—	—	25/33.3	28/37.3
	EVER-Tap	833	1093	933	1224	1108	1454	1241	1628	1388	1822	1524	2000	25/33.3/41.7	28/37.3/45.7
	QD8	1000	1312	1120	1469	1330	1745	1490	1954	—	—	—	—	30/40	33.6/44.8
	EVER-Tap	1000	1312	1120	1469	1330	1745	1490	1954	1524	2000	1524	2000	30/40/45.7	33.6/44.8/45.7
	EVER-Tap	1166	1530	1306	1714	1524	2000	1524	2000	—	—	—	—	35/45.7	39/45.7
	QD8	1166	1530	1306	1714	1551	2035	1737	2279	1943	2550	2176	2856	35/46/58	39/52/65
14400/24940Y	QD8	333	231	373	259	443	307	496	344	—	—	—	—	10/12.5	11.2/14
	QD8	432	300	484	336	575	399	644	447	—	—	—	—	13/17.2	14.5/19.3
	QD8	500	347	560	389	665	462	745	517	—	—	—	—	15/20	16.8/22.3
	QD8	576	400	645	448	766	532	858	596	—	—	—	—	17.3/22.4	19.4/25.7
	QD8	667	463	747	519	887	616	994	690	—	—	—	—	20/26.7	22.4/29.9
	EVER-Tap	667	463	747	519	887	616	994	690	1112	772	1245	864	20/26.7/33.3	22.4/29.9/37.3
	QD8	833	578	933	647	1108	769	1241	861	—	—	—	—	25/33.3	28/37.3
	EVER-Tap	833	578	933	647	1108	769	1241	861	1388	963	1555	1079	25/33.3/41.7	28/37.3/46. 7
	EVER-Tap	1000	693	1120	776	1330	922	1490	1032	1667	1155	1867	1294	30/40/50	33.6/44.8/56
19920/34500Y	QD8	333	167	373	187	443	222	496	249	—	—	—	—	10/12.6	11.2/14
	QD8	400	200.8	448	225	532	267	596	299	—	—	—	—	12/16	13.4/17.9
	QD8	500	251	560	281	665	334	745	374	—	—	—	—	15/20	16.8/22.3
	QD8	667	334	747	374	887	444	994	498	—	—	—	—	20/26.7	22.4/29.9
	EVER-Tap	667	334	747	374	887	444	994	498	1112	557	1245	623	20/26.7/33.3	22.4/29.9/37.3
	QD8	833	418	933	468	1108	556	1241	623	—	—	—	—	25/33.3	28/37.3
	EVER-Tap	833	418	933	468	1108	556	1241	623	1388	697	1555	780	25/33.3/41.7	28/37.3/46.7
	EVER-Tap	1000	502	1120	562	1330	668	1490	748	1667	837	1867	937	30/40/50	33.6/44.8/56

An example of cost comparisons for the three voltage regulating alternatives in the substation are shown below in Table 2.

Table 2. Life cycle cost evaluation

30/40/50 MVA load 115 kV/24.9 kV) application	Initial cost	Installation cost	Warranty	Recommended inspection interval	Estimated maintenance interval	Estimated maintenance cost
Power transformer/ vacuum interrupting OLTC	$1,800,000*	Pad = $2000 Crane = $700/hr - 3 hrs Total = $ 4,200	One (1) year from installation/ 18 months from shipment	Power transformer = 1 year OLTC = 500,000 operations	Power transformer = 10 years OLTC = 1,000,000 operations	Spare power transformer = $1,500,000 Mobile single-phase EVER-Tap vacuum interrupting voltage regulator = $600,000 Two-week maintenance = $300,000 Control upgrade = $3,000
Power transformer with three single-phase EVER-Tap vacuum interrupting voltage regulators	$1,750,000	Bypass/Disconnect = $15,000 Pads = $3,000 Crane = $700/hr - 4 hrs Total = $20,800	Power transformer - one (1) year from installation/ 18 months from shipment Eaton EVER-Tap = 3 years from installation	Power transformer and voltage regulators = 1 year Eaton EVER-Tap = 500,000 operations	Power transformer and voltage regulators = 10 years Eaton EVER-Tap = 1,000,000 operations	Spare power transformer = $1,500,000 Spare voltage regulator = $100,000 Two-week maintenance = $300,000 Control upgrade = $3,000
Power transformer with three single-phase fluid-interrupting voltage regulators	$1,600,000	Bypass/Disconnect = $15,000 Pads = $3,000 Crane = $700/hr - 4 hrs Total = $20,800	One (1) year from installation/ 18 months from shipment	Power transformer and voltage regulators = 1 year Eaton QD8 tap changer = 5 years 50,000 operations	Power transformer and voltage regulators = 10 years Eaton QD8 tap changer = 10 years or 100,000 operations	Spare power transformer = $1,500,000 Spare voltage regulator = $60,000 Two-week maintenance = $300,000 Control upgrade = $3,000

**The numbers in this table are estimates based on typical installation and maintenance costs. Actual costs may vary.*

For more information, please visit
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