

ETAP Motor Starting Analysis

The ETAP V&V process for the Motor Starting program has over 1600 test case scenarios that are run before each ETAP release. The following cases are excerpts from the Motor Starting V&V documentation.

Motor Starting Comparison Case # 1

Comparison of ETAP Motor Starting with Torque Control Against Hand Calculated Results

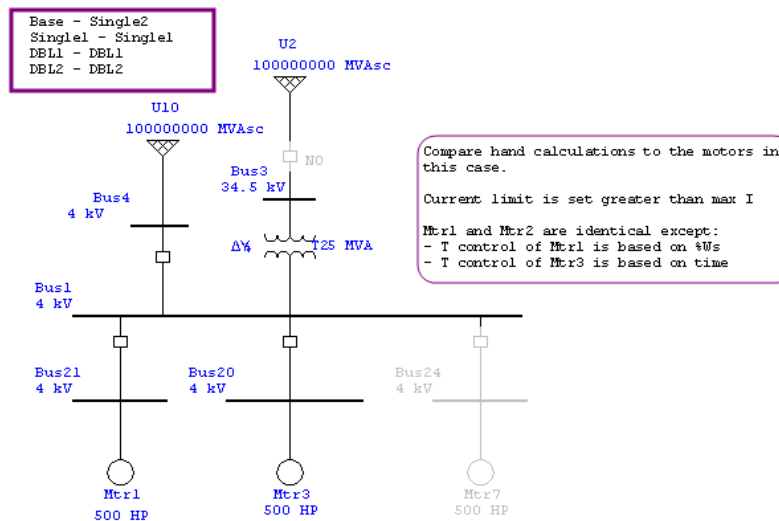
Excerpts from Validation Cases and Comparison Results (TCS-MS-149)

Highlights

- Comparison of ETAP Motor acceleration results against Hand Calculations.
- Torque Control Solid-State Motor Starting Device is used to start the motor.
- Single1, Single2, Double1 and Double2 CKT models are used in the hand calculation.
- Motor is rated at 500 HP at 4 kV, RPM = 1800, %PF = 89.85 and %Eff = 94.14.
- The compared results include the motor Power Output, Reactive Power Input, Motor Current, Terminal Voltage and Power Factor at different Slip values.
- Hand Calculations were accomplished using MathCAD version 2000. The equations for the motor modeling were obtained from different sources.
- The same system was used for the different motor CKT models.

System Description

This is a 3-Phase system that consists of three induction motors. One of the induction motors at the 0.480 kV bus is being started at $t = 0$ sec. The CKT model parameters are as shown on the Model page. The motor being started is **50St100Ld-1**.



The following is a sample of the hand calculations that were performed for each motor model.

Hand Calc's

Single2 Model:

$$\text{MotorkV} := 4$$

$$\text{MotorMVA} := 0.4408$$

$$Z_B := \frac{\text{MotorkV}^2}{\text{MotorMVA}} \quad Z_B = 36.29764 \quad R_{2LR} := 0.0123 Z_B \quad R_{2LR} = 0.44646$$

$$R_1 := 0.0383 Z_B \quad R_{2FL} := 0.0152 Z_B \quad R_{2FL} = 0.55172$$

$$X_1 := 0.1029 Z_B \quad X_{2LR} := 0.093 Z_B \quad X_{2LR} = 3.37568$$

$$X_m := 3.652 Z_B \quad X_{2FL} := 0.1167 Z_B \quad X_{2FL} = 4.23593$$

Find rated slip using trial and error until current (I1) is satisfied:

$$s_{\text{rated}} := 0.0155022$$

$$R_2 := (R_{2FL} - R_{2LR}) \cdot (1 - s_{\text{rated}}) + R_{2LR} \quad R_2 = 0.55009$$

$$X_2 := (X_{2FL} - X_{2LR}) \cdot (1 - s_{\text{rated}}) + X_{2LR} \quad X_2 = 4.2226$$

$$Z_{\text{eq}} := R_1 + X_1 i + \left(\frac{1}{X_m i} + \frac{1}{\frac{R_2}{s_{\text{rated}}} + X_2 \cdot i} \right)^{-1} \quad Z_{\text{eq}} = 32.61631 + 15.92816i$$

$$I_1 := \frac{\frac{\text{MotorkV} \cdot 1000}{\sqrt{3}}}{|Z_{\text{eq}}|} \quad I_1 = 63.62373$$

Calculate the relationship (K) between Pout and Pag to compensate for rotational losses:

$$\text{PF} := \cos(\arg(Z_{\text{eq}})) \quad \text{PF} = 0.89858$$

$$P_{\text{ag}} := \sqrt{3} \cdot \text{MotorkV} \cdot I_1 \cdot \text{PF} - \frac{(3I_1^2 \cdot R_1)}{1000} \quad P_{\text{ag}} = 379.20791$$

$$P_{\text{conv}} := (1 - s_{\text{rated}}) \cdot P_{\text{ag}} \quad P_{\text{conv}} = 373.32935$$

$$P_{\text{out}_{\text{rated}}} := 500 - 0.7457 \quad P_{\text{out}_{\text{rated}}} = 372.85$$

$$K_{\text{ga}} := \frac{P_{\text{ag}}}{P_{\text{out}_{\text{rated}}}} \quad K_{\text{ga}} = 1.01705$$

Comparison of Results

The following tables of comparisons illustrate the comparisons made between ETAP Motor Starting and the MathCAD hand calculations. Please note that in all cases, the % difference for all the compared parameters is less than 0.1%.

Single2 Model:

		Benchmark		ETAP		% Diff	
S (pu)	t (s)	P (kW)	Q (kvar)	P (kW)	Q (kvar)	P (%)	Q (%)
0.899978	0.876	7.45864	1558.67	7.45861	1558.58	0.0	0.0
0.699989	2.362	32.1615	1605.76	32.1615	1605.66	0.0	0.0
0.689957	2.416	35.0731	1634.12	35.0731	1634.02	0.0	0.0
0.670009	2.517	41.2157	1684.88	41.2158	1684.78	0.0	0.0
0.62994	2.722	47.4067	1647.67	47.4068	1647.57	0.0	0.0
0.55019	3.237	58.7214	1542.35	58.7214	1542.26	0.0	0.0
0.250022	4.417	332.613	1749.12	332.525	1749	0.0	0.0
0.013967	10	336.174	179.364	336.174	179.312	0.0	0.0

Double1 Model:

		Benchmark		ETAP		% Diff	
S(pu)	t (s)	P (kW)	Q (kvar)	P (kW)	Q (kvar)	P (%)	Q (%)
0.900043	1.369	5.59035	2332.06	5.59033	2332.38	0.0	0.0
0.749985	2.831	17.7119	2400.7	17.7119	2401.03	0.0	0.0
0.739948	2.911	18.7474	2405.82	18.7473	2406.15	0.0	0.0
0.720057	3.072	20.8734	2414.29	20.8734	2414.61	0.0	0.0
0.690032	3.331	23.6091	2389.87	23.6091	2390.19	0.0	0.0
0.619981	4.126	29.7549	2299.64	29.7549	2299.95	0.0	0.0
0.499961	5.21	73.4686	2829.61	73.4686	2829.61	0.0	0.0
0.249992	7.744	215.571	2794.31	215.571	2794.69	0.0	0.0
0.003514	10	344.09	168.2	344.09	168.321	0.0	0.1

Double2 Model:

		Benchmark		ETAP		% Diff	
S(pu)	t (s)	P (kW)	Q (kvar)	P (kW)	Q (kvar)	P (%)	Q (%)
0.89999	1.364	5.5933	1072.45	5.5933	1072.48	0.0	0.0
0.749945	2.82	17.716	1136.02	17.716	1136.06	0.0	0.0
0.739993	2.899	18.7427	1141.19	18.7426	1141.23	0.0	0.0
0.720021	3.06	20.8773	1151.11	20.8773	1151.15	0.0	0.0
0.689995	3.318	23.6125	1149.11	23.6126	1149.14	0.0	0.0
0.620011	4.109	29.7526	1132.15	29.7526	1132.19	0.0	0.0
0.499838	4.515	408.839	3357.97	408.84	3358.07	0.0	0.0
0.249964	4.677	578.276	2995.05	578.275	2995.15	0.0	0.0
0.003522	10	344.084	164.803	344.084	164.83	0.0	0.0

Table 14: Comparison of ETAP Motor Starting Results with a Torque Control Starting Device against Hand Calculations at various Motor Slip points.

Single1 Model:

S (pu)	t (s)	Benchmark		ETAP		% Diff	
		P (kW)	Q (kvar)	P (kW)	Q (kvar)	P (%)	Q (%)
0.900008	0.835	7.4564	1473.97	7.45639	1473.88	0.0	0.0
0.699987	2.252	32.1621	1555.32	32.162	1555.22	0.0	0.0
0.690051	2.303	35.0452	1585.36	35.0451	1585.26	0.0	0.0
0.66996	2.4	41.2247	1640.66	41.2247	1640.55	0.0	0.0
0.629982	2.595	47.4	1610.61	47.4	1610.5	0.0	0.0
0.550047	3.086	58.7177	1518.09	58.7177	1518	0.0	0.0
0.249183	3.67	1209.53	3005.72	1209.53	3005.72	0.0	0.0
0.01304	10	336.877	174.338	336.877	174.495	0.0	0.1

Table 15: Comparison of ETAP Motor Starting Results with a Torque Control Starting Device against Hand Calculations at various Motor Slip points.

Characteristic Model:

S (pu)	t (s)	Benchmark			
		V (%)	I (%)	PF (%)	Q (kvar)
0.900083	0.838	72.2158	359.635	25.803	1557.5
0.689961	2.354	76.409	373.631	27.883	1609.15
0.67999	2.407	77.88	380.351	28.024	1636.17
0.599963	2.822	78.7452	380.733	29.146	1633.47
0.500036	3.645	72.5149	344.736	31.038	1480.61
0.013515	10	99.9902	144.196	82.498	359.303

S (pu)	t (s)	ETAP			
		V (%)	I (%)	PF (%)	Q (kvar)
0.900083	0.838	72.2145	359.664	25.79	1557.54
0.689961	2.354	76.4068	373.627	27.872	1609.03
0.67999	2.407	77.8787	380.353	28.012	1636.07
0.599963	2.822	78.7406	380.735	29.14	1633.38
0.500036	3.645	72.5145	344.72	31.03	1480.44
0.013515	10	100.008	144.195	82.49391	359.351

S (pu)	t (s)	% Diff			
		V (%)	I (%)	PF (%)	Q (kvar)
0.900083	0.838	-0.0	0.0	-0.1	0.0
0.689961	2.354	-0.0	-0.0	0.0	0.0
0.67999	2.407	-0.0	0.0	0.0	0.0
0.599963	2.822	-0.0	0.0	0.0	0.0
0.500036	3.645	-0.0	-0.0	0.0	0.0
0.013515	10	0.0	-0.0	0.0	0.0

Table 16: Comparison of ETAP Motor Starting Results with a Torque Control Starting Device against Hand Calculations at various Motor Slip points.

Reference

1. ETAP Motor Starting V&V Documents, Case Number TCS-MS-149.