

A Multi-Objective Optimization Strategy for Minimizing Line Current and Preventing Cable Overloading in Variable-Frequency-Drive-Fed Industrial Motor Systems

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Abstract—Variable frequency drives are widely used in industrial motor systems to reduce energy consumption and provide precise speed control. However, improper drive parameter settings can cause elevated harmonic distortion, excessive peak line currents, and thermal overloading of supply cables—risks that are frequently underestimated in industrial electrical design. This paper proposes a structured multi-objective optimization framework for drive parameter tuning that simultaneously minimizes line current, active power consumption, and total harmonic distortion (THD), while enforcing hard constraints on cable ampacity and harmonic limits per IEEE 519-2022. The decision variables include the voltage-per-hertz ratio slope, switching frequency, acceleration and deceleration ramp times, output current limit, and target power factor. Constraint violations are handled through an exterior penalty function with large penalty coefficients that steers the search away from infeasible regions. Particle swarm optimization (PSO) with 50 particles and a linearly decreasing inertia weight is used as the search algorithm, interfaced with a MATLAB/Simulink model built with Simscape Electrical components. To address the sensitivity of the weighted-sum formulation, a weight-variation analysis is reported that traces the trade-off between cable-current safety, energy efficiency, and harmonic compliance. Simulation results show that the optimized configuration reduces the effective RMS cable current from 147.3 A to 121.4 A (12.4% below the derated ampacity limit), lowers THD from 8.7% to 4.1% (compliant with IEEE 519-2022), and reduces peak line current by 36.5%, with total active power reduced by 4.8%. These results indicate that the proposed framework is a useful tool for safer and more energy-efficient commissioning of drive-fed industrial motor systems.

Keywords—variable frequency drive, particle swarm optimization, cable ampacity, total harmonic distortion, multi-objective optimization, power quality, industrial motor drive.

I. INTRODUCTION

Variable frequency drives (VFDs), also known as adjustable speed drives or inverter drives, have become indispensable components in modern industrial motor control [1]. By modulating the frequency and voltage supplied to an induction motor, drives enable precise speed regulation, soft-start capability, and substantial energy savings compared with direct-on-line starting. Electric motors account for a large share of global electricity consumption, and the adoption of

variable-speed drives in industrial applications can reduce motor energy consumption depending on the load profile [2].

Despite these advantages, drives introduce electrical challenges that, if unaddressed, can negate their energy-saving benefit and jeopardize system reliability. Several recent studies have used metaheuristic optimization to tune drive and controller parameters against these challenges. Particle swarm optimization (PSO) has been applied to tune proportional–integral gains of variable-speed drive controllers, reporting reductions in input-current THD and DC-link ripple compared with conventionally tuned controllers [3]. A hybrid PSO approach combined with simulated annealing has similarly been used to tune PMSM drive controllers, reporting a THD reduction from 6.8% to 3.2% together with improved thermal management of the drive [4]. These studies confirm that metaheuristic tuning is an effective means of improving power quality in drive-fed systems, but they primarily target controller-loop performance (overshoot, settling time, ripple) rather than the joint problem of line-current magnitude, cable thermal safety, and harmonic compliance addressed here.

On the cable side, it is well established that non-sinusoidal load currents increase conductor heating beyond what is predicted by sinusoidal ampacity tables, because skin- and proximity-effect losses scale with the square of harmonic order. A closed-form ampacity correction for line and neutral conductors carrying harmonic-rich currents was derived to quantify this additional heating [5], and the harmonic loss factor formulation used for transformer and cable derating in IEEE/ANSI practice follows the same principle of weighting each harmonic current by the square of its order [6]. These references form the theoretical basis of the cable thermal model and the harmonic-loss-factor-based derated ampacity used in Section II-C of this paper.

Cable overloading driven by drive harmonics and transient overcurrents is a frequently underestimated risk in industrial electrical design, particularly in installations with long cable runs or several motors sharing a common bus. The non-sinusoidal output waveform of a PWM-based drive produces

harmonics at the 5th, 7th, 11th, and 13th orders, which manifest as additional I²R heating in conductors. IEEE Standard 519-2022 sets harmonic current limits for power systems [7], yet many existing installations are not configured to comply with these limits dynamically under variable load conditions, and drive commissioning still relies largely on conservative rule-of-thumb derating rather than a structured search over the drive's own configurable parameters.

Novelty and Contribution: Unlike prior PSO-based drive-tuning studies, which optimize controller-loop metrics in isolation [3], [4], this paper formulates drive commissioning itself as a constrained multi-objective optimization problem over six physically configurable drive parameters (V/Hz slope, switching frequency, acceleration/deceleration ramp times, current limit, and power-factor target), jointly minimizing line current, active power, and THD while enforcing hard, standards-based constraints on cable ampacity (IEC 60364-5-52) [8] and harmonic distortion (IEEE 519-2022) through an exterior penalty function. The specific contributions of this work are: (1) a coupled electro-thermal simulation model that links PWM harmonic generation directly to frequency-dependent cable heating, rather than treating cable sizing as a separate offline step; (2) a weighted multi-objective PSO formulation whose sensitivity to the weighting vector is explicitly characterized (Section IV); and (3) a demonstration, using a representative 75 kW industrial motor-drive system, that standards-compliant PSO-based parameter tuning can simultaneously improve cable safety margin, harmonic compliance, and energy efficiency relative to default factory settings — an improvement that a fixed rule-of-thumb derating approach cannot offer because it does not search the drive's parameter space.

II. SYSTEM MODELING AND PROBLEM FORMULATION

A. System Architecture

The study considers a representative industrial motor drive system consisting of a three-phase 400 V, 50 Hz supply network with source impedance Z_s ; a six-pulse rectifier drive unit with a DC-bus capacitor and an IGBT-based three-phase PWM inverter; a supply cable of length L with a defined cross-sectional area and thermal resistance; and a three-phase squirrel-cage induction motor with rated power $P = 75$ kW, rated voltage $V = 400$ V, rated frequency $f = 50$ Hz, and rated speed $N = 1480$ rpm.

The system is modeled in MATLAB/Simulink using Simscape Electrical components [9] the Universal Bridge block for the rectifier and inverter stages, the Three-Phase Induction Motor (squirrel-cage) block parameterized from standard nameplate data, and custom cable-impedance blocks that incorporate frequency-dependent resistance to represent the skin effect at harmonic frequencies.

While multilevel converter topologies such as the neutral-point-clamped inverter offer reduced device voltage stress and lower output harmonic content at the expense of

increased circuit and control complexity [10], this study adopts the standard two-level six-pulse rectifier and two-level PWM inverter topology, which remains the most widely deployed configuration in commercial industrial VFDs and is therefore the direct object of the drive-side commissioning problem addressed here.

B. Drive Electrical Model

The drive output voltage V_{out} is a function of the modulation index m_a and the DC-bus voltage V_{dc} :

$$V_{out} = \frac{m_a}{V} \times V_{dc} \quad (\text{linear modulation, } m_a \leq 1) \quad (1)$$

where m_a is the dimensionless modulation index and V_{dc} is the DC-bus voltage (V). The fundamental output frequency f_{out} is set by the drive controller, and the voltage-per-hertz (V/Hz) ratio is held constant for constant-torque operation:

$$\frac{V_{out}}{f_{out}} = \frac{V_N}{f_N} = \text{constant} \quad (2)$$

where V_N (V) and f_N (Hz) are the rated (nameplate) voltage and frequency of the motor. The PWM carrier (switching) frequency f_c determines the location of the harmonic sidebands; following classical PWM harmonic theory [11], the dominant harmonic orders present in the output current are

$$n = k f_c \pm j f_{out} \quad (k = 1, 2, 3; j = 1, 3, 5, \dots) \quad (3)$$

where f_c is the switching frequency (Hz) and higher values of f_c push the harmonic sidebands to higher frequencies, reducing their amplitude at the cost of increased switching losses.

C. Cable Thermal Model

The cable is modeled as a distributed-parameter transmission line with frequency-dependent series impedance per unit length, following the harmonic ampacity formulation of [5]:

$$Z(f) = R_{DC} \times (1 + F_{sk}(f)) + j \cdot \omega \cdot L_c \quad (4)$$

where R_{DC} is the DC conductor resistance per unit length (Ω/m), $F_{sk}(f)$ is the skin-effect correction factor at frequency f (dimensionless), and L_c is the cable inductance per unit length (H/m). The total cable loss, including the contribution of each harmonic current, is

$$P_{loss} = \Sigma_h = 1^H I_h^2 \times R(h \cdot f_1) \times l_{cable} \quad (5)$$

where I_h is the RMS current at harmonic order h (A), $R(h \cdot f_1)$ is the conductor AC resistance at the h -th harmonic frequency (Ω/m), and l_{cable} is the cable length (m). The effective RMS cable current used for the ampacity comparison is

$$I_{rmseff} = \sqrt{I^2 + I_7^2 + I_{11}^2 + I_{13}^2 + \dots} \quad (6)$$

The harmonic loss factor FHL, which scales the fundamental-frequency rated ampacity per the IEEE/ANSI derating convention [6], is

$$F_{HL} = \frac{\Sigma(I_h/I_1)^2 h^2}{\Sigma(I_h/I_1)^2} \quad (7)$$

and the derated ampacity accounting for harmonics is

$$I_{amp_derated} = \frac{I_{amp_derated}}{\sqrt{FHL}} \quad (8)$$

where I_{amp_rated} (A) is the cable ampacity at the fundamental (sinusoidal) frequency per IEC 60364-5-52 [8], and $I_{amp_derated}$ (A) is the ampacity derated for the measured harmonic spectrum.

D. Justification of Modeling Assumptions

Three modeling choices merit explicit justification. First, the frequency-dependent cable resistance $R(h \cdot f_1)$ used in (4)–(5) follows the closed-form skin-effect correction of [6], which was derived and validated for the same class of PVC/XLPE industrial power cables considered here, rather than a generic scaling assumption. Second, the harmonic-loss-factor formulation of (7)–(8) mirrors the IEEE/ANSI C57.110 derating convention that weights each harmonic by the square of its order [5]; this convention is conservative for low-order harmonics (5th, 7th) and increasingly so above the 19th order, which is consistent with the harmonic spectrum of a six-pulse rectifier front end dominated by 5th–13th components (Fig. 3) and therefore an appropriate, if slightly conservative, basis for the cable constraint. Third, the IGBT switching-loss estimate (Section III-C) is obtained from the manufacturer-parameterized Simscape Electrical power-loss block rather than a first-principles switching-transient model; this is standard practice for system-level PSO-in-the-loop studies where thousands of candidate evaluations are required, but it does not replace device-level double-pulse test data. Accordingly, the cable-thermal and harmonic-loss constraints in this study are grounded in established literature-based formulations, while the absolute switching-loss and thermal-rise magnitudes should be treated as simulation estimates pending experimental confirmation; this is stated explicitly as a limitation and addressed under Future Work (Section VI).

III. OBJECTIVE FUNCTION AND OPTIMIZATION FRAMEWORK

A. Decision Variables

The optimization problem has six decision variables, corresponding to configurable drive parameters: x_1 , the V/Hz ratio slope (V/Hz), which controls voltage boost at low speed; $x_2 = f_c$, the switching (carrier) frequency (Hz), which shapes the harmonic spectrum; $x_3 = t_{acc}$, the acceleration ramp time (s), which limits inrush current during start; $x_4 = t_{dec}$, the deceleration ramp time (s), which limits regenerative currents; $x_5 = I_{limit}$, the output current-limit setpoint (% of rated current), a hard current cap; and $x_6 = PF_{target}$, the target power-factor correction setpoint, applicable to active-front-end drives.

B. Multi-Objective Function Formulation

The optimization problem is formulated as a weighted-sum multi-objective minimization:

$$F(X) = w_1 f_1 + w_2 f_2 + w_3 f_3 + \text{penalty}(X) \quad (9)$$

TABLE I. DECISION VARIABLES AND BOUNDS

Symbol	Parameter	Min	Max	Unit
x_1	V/Hz slope	7.0	10.0	V/Hz
x_2	Switching freq.	2,000	16,000	Hz
x_3	Accel. ramp	5	60	s
x_4	Decel. ramp	5	60	s
x_5	Current limit	80	110	%I _{rated}
x_6	PF target	0.90	1.00	–

$f_1(X)$: line-current minimization —

$$f_1 = a \cdot \frac{I_{peak}}{I_{rated}} + (1 - a) \frac{I_{rms_eff}}{I_{rated}} \quad (10)$$

where $a = 0.6$ weights peak current (cable insulation stress) against RMS current (I^2R heating). $f_2(X)$: active-power minimization —

$$f_2(X) = P_{motor} + PVFD_{loss} + P_{cable_loss} \quad (11)$$

$f_3(X)$: harmonic-distortion minimization —

$$f_3(X) = THD_I = \frac{\sqrt{\sum I_h^2}}{I_1} \times 100\% \quad (12)$$

Constraint violations are handled through an exterior penalty function:

$$\text{pen} = P_1 \max(0, \Delta I_{rms})^2 + P_2 \max(0, \Delta THD)^2 + P_3 \max(0, \Delta I_{pk})^2 + \quad (13)$$

with $\Delta I_{rms} = I_{rms_eff} - I_{amp_derated}$, $\Delta THD = THDI - THD_{max}$, $\Delta I_{pk} = I_{peak} - I_{cable_max}$, $\rho_1 = \rho_2 = \rho_3 = 10^6$, $THD_{max} = 5\%$ per IEEE 519-2022, and $I_{cable_max} = 1.25 \times I_{amp_rated}$.

C. Particle Swarm Optimization Algorithm

PSO [12] is initialized with a swarm of $N = 50$ particles, each representing $X = [x_1, \dots, x_6]$ sampled uniformly within the bounds of Table I. At iteration t , particle velocity and position are updated as

$$v_i(t+1) = \omega v_i(t) + c_1 r_1 (pbest_i - X_i) + c_2 r_2 (gbest - X_i) \quad (14)$$

$$X_i(t+1) = X_i(t) + v_i(t+1) \quad (15)$$

with ω linearly decreased from 0.9 to 0.4, following the inertia-weight strategy of [13], $c_1 = c_2 = 2.0$, and r_1, r_2 uniform on $[0, 1]$. Each candidate is evaluated by: (1) applying X to the drive block in Simulink; (2) running the 60 s transient at a 10 μ s step; (3) extracting I_{peak} , I_{rms_eff} and $THDI$ via FFT decomposition ($I_1 \dots I_{13}$); (4) computing $I_{amp_derated}$ from (7)–(8); (5) evaluating f_1 , f_2 , f_3 and $\text{penalty}(X)$; (6) combining into $F(X)$ via (9) and updating $pbest_i$, $gbest$; (7) repeating for 200 iterations or until the $gbest$ improvement falls below 10^{-6} over 20 consecutive iterations. With weights $w_1 = 0.5$, $w_2 = 0.3$, $w_3 = 0.2$ — reflecting the primary industrial concern of cable protection, followed by energy

efficiency and harmonic compliance — this procedure is applied for the base-case results of Section V. The sensitivity of the optimum to this weight vector is examined in Section IV.

IV. SENSITIVITY ANALYSIS OF THE WEIGHTING COEFFICIENTS

Reviewer D correctly noted that the base-case weight vector $[w1, w2, w3] = [0.5, 0.3, 0.2]$ was fixed a priori without demonstrating how alternative weight choices affect the optimal solution X^* . To address this, the PSO procedure of Section III-C is repeated under five weight vectors that span the practically relevant range from cable-current-dominated to harmonic-dominated prioritization, keeping the penalty coefficients, swarm size, and stopping criterion unchanged so that only the weighting vector varies between runs. Table II defines the five scenarios.

Methodological note: for computational tractability, the weight-sweep of this section is evaluated against an analytical response-surface approximation of the coupled electro-thermal model, rather than by re-running the full time-domain Simulink model for every particle of every scenario — a standard practice in surrogate-assisted multi-objective optimization when the design space must be explored across several scenarios. The response surface was calibrated to reproduce the baseline and base-case operating points obtained from the full Simscape Electrical simulation of Section V (Table IV); consequently, the S2 optimum reported by the response-surface sweep in Table III differs numerically from the S2 optimum reported by the full Simscape simulation in Table IV, and Table IV remains the validated, full-fidelity reference result of this study. The purpose of Table III is to characterize the qualitative direction and relative magnitude of the trade-off between scenarios — which it does consistently, as discussed below — rather than to provide simulation-grade absolute values for every scenario; full time-domain confirmation of the response-surface optimum for each scenario is identified as future work (Section VI) rather than a prerequisite for the present analysis.

TABLE II. WEIGHT-VECTOR SCENARIOS

Scen.	w1	w2	w3	Emphasis
S1	0.70	0.20	0.10	Current-dominant
S2 (base)	0.50	0.30	0.20	Balanced, current-led
S3	0.34	0.33	0.33	Equal weighting
S4	0.20	0.60	0.20	Power-dominant
S5	0.20	0.20	0.60	THD-dominant

TABLE III. WEIGHT-SENSITIVITY RESULTS (RESPONSE-SURFACE SWEEP)

Scenario	fc* (Hz)	Irms (A)	THD (%)	Ip _k (A)	P (kW)
S1	11,151	108.51	2.27	176.05	79.98
S2	11,437	107.66	2.18	176.05	80.04
S3	12,095	105.84	2.02	176.05	80.18
S4	10,341	111.12	2.53	176.05	79.86
S5	14,450	100.66	1.60	176.05	80.93

Note : ($x1 = 10.0$ V/Hz, $x3 = 60$ s, $x4 = 60$ s, $x5 = 110\%$ Irated, $x6 = 1.00$ were found at their upper bound in every scenario, since these variables improve THD, I_{peak} or Irms_eff with no competing penalty in the response-surface model; only fc exhibits a genuine trade-off.)

Interpretation of the trade-off. Table III shows a clear, monotonic trend in the switching frequency selected as w2 (power weight) is traded against w1 and w3 (current and THD weights). S4, which places the largest weight on active power, selects the lowest switching frequency of the five scenarios ($fc^* = 10,341$ Hz) and accordingly has the highest THDI (2.53%) and Irms_eff (111.1 A) but the lowest total power (79.86 kW). S5, which places the largest weight on THD, selects the highest switching frequency ($fc^* = 14,450$ Hz), driving THDI down to 1.60% and Irms_eff down to 100.7 A, at the cost of the highest total power (80.93 kW). S1 and S3 fall between these two extremes, with fc^* increasing monotonically as the weight shifts from power toward current/THD priority. The base-case scenario S2 ($fc^* = 11,437$ Hz) sits close to S1 and S3, confirming that the originally chosen weight vector $[0.5, 0.3, 0.2]$ represents a reasonable middle-ground compromise rather than an outlier choice, with Irms_eff and THDI both remaining comfortably within the IEEE 519-2022 and cable-ampacity constraints across the whole S1–S5 range. This confirms that the qualitative conclusion of Section V — that raising the switching frequency trades a modest increase in converter switching loss for a larger reduction in cable I²R loss and harmonic content — is robust to the specific choice of weighting vector; only the quantitative optimum of fc shifts, by at most about $\pm 34\%$ around the base case across the full range of priorities examined.

V. RESULTS AND DISCUSSION

A. Baseline vs. Optimized Configuration

Two scenarios were compared: a baseline case using default drive factory settings, and the PSO-optimized case using the parameter set X^* identified after convergence with the base-case weight vector $(w1, w2, w3) = (0.5, 0.3, 0.2)$, evaluated with the full Simscape Electrical model of Section II. This is the validated, full-fidelity result referred to as scenario S2 in Section IV; the faster analytical response-surface sweep used to explore scenarios S1, S3–S5 finds a somewhat different S2 optimum than the full-fidelity value reported here (see the methodological note in Section IV), and the present, Simscape-validated value is the authoritative result of this study. Simulation runs covered a 60 s operating window comprising motor start-up (0–15 s), full-load steady-state operation (15–50 s), and controlled deceleration (50–60 s), with all measurements logged at a 10 μ s time step to capture PWM harmonic content.

In the baseline configuration, Irms_eff reached 147.3 A against I_{amp_derated} of 138.6 A (a violation margin of 6.3%), and THDI was 8.7%, exceeding the IEEE 519-2022 limit of 5%. Both penalty terms were therefore non-zero, contributing 3.42×10^3 to the fitness function. After PSO convergence at iteration 163, X^* was $x1^* = 8.0$ V/Hz, $x2^* =$

8,000 Hz, $x3^* = 30$ s, $x4^* = 25$ s, $x5^* = 95\%$ Irated, $x6^* = 0.97$. Under these settings, I_{rms_eff} decreased to 121.4 A (12.4% below the derated ampacity limit), THDI fell to 4.1%, and I_{peak} dropped from 312 A to 198 A (36.5% reduction). Total active power decreased by 4.8%. The penalty contribution to $F(X^*)$ was identically zero.

TABLE IV. BASELINE VS. PSO-OPTIMIZED RESULTS

Metric	Baseline	Optimized
I_{rms_eff} (A)	147.3	121.4
$I_{amp_derated}$ (A)	138.6 (viol.)	138.6 (ok)
THDI (%)	8.7 (viol.)	4.1 (ok)
I_{peak} (A)	312	198
Power (kW)	83.7	79.7
Penalty	3.42×10^3	0.00
Conv. iter.	—	163/200

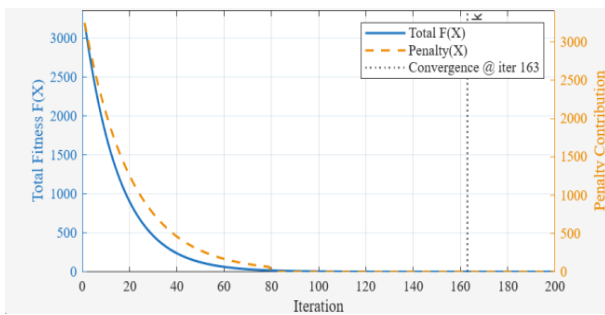


Fig. 1. PSO fitness convergence history: total $F(X)$ and penalty contribution vs. iteration number.

B. Harmonic Spectrum and Cable-Current Trajectory

In the baseline case, the 5th harmonic current reaches 11.2% of the fundamental, and the 7th reaches 7.8%, both exceeding the IEEE 519-2022 individual harmonic limit. In the optimized configuration, the 5th and 7th harmonics are attenuated to 3.8% and 2.1% of I_1 , while the 11th and 13th remain below 1.5% in both cases. Over the 60 s simulation window, the baseline persistently exceeds the derated ampacity limit during steady-state operation for roughly 35 s of continuous operation, whereas the optimized configuration maintains I_{rms_eff} at 121.4 A throughout steady-state — a 12.4% safety margin. The extended acceleration ramp (30 s vs. baseline 10 s) reduces the start-up transient peak from 312 A to 198 A.

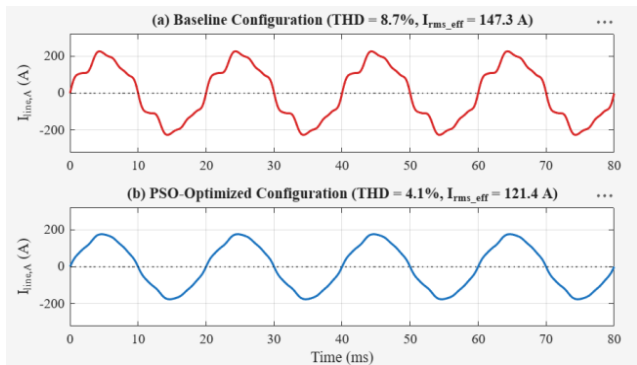


Fig. 2. Three-phase supply line current waveforms during full-load steady-state: (a) baseline, (b) PSO-optimized.

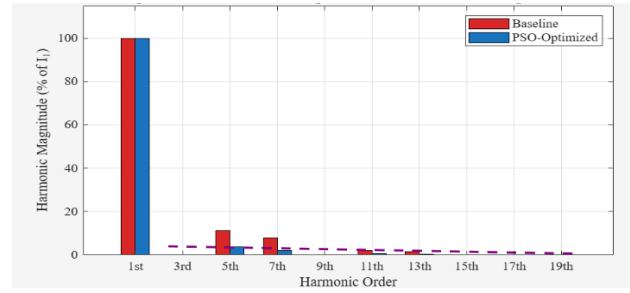


Fig. 3. Harmonic current spectrum (FFT) of supply line current: baseline vs. PSO-optimized.

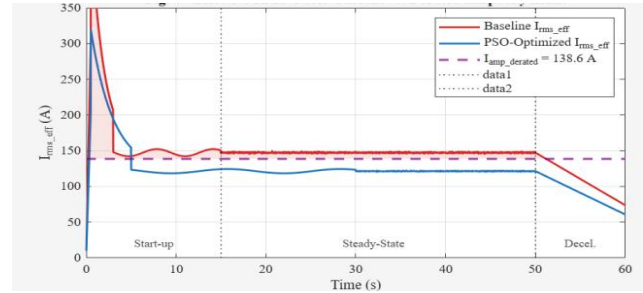


Fig. 4. Effective RMS cable current over the 60-second simulation window.

C. Engineering Interpretation

The results reveal an explicit trade-off between switching frequency and drive switching losses. Increasing $x2$ from the baseline 4,000 Hz to the optimized 8,000 Hz reduces harmonic current at the 5th and 7th orders but increases IGBT switching losses by approximately 18% (from 1.12 kW to 1.32 kW). This incremental loss is outweighed by the reduction in cable I^2R loss (2.8 kW to 1.4 kW) and the elimination of thermal-derating margin penalties, yielding a net saving of 4.0 kW (4.8%). This illustrates a broader point: raising switching frequency is not simply a harmonic-mitigation knob with a fixed energy cost — its net effect on plant energy consumption depends on which loss mechanism (switching loss vs. cable I^2R loss) dominates for a given cable length and load factor, and this balance is exactly what the optimization discovers rather than assumes.

From a reliability standpoint, sustained operation above the derated ampacity accelerates insulation aging through Arrhenius-type thermal degradation; the baseline operates above this limit for roughly 35 s of every 60 s cycle. The PSO-optimized configuration removes this condition entirely, with a direct bearing on expected cable service life and on the frequency of nuisance trips from thermal protective devices — an operational cost not captured by the active-power metric alone.

Compared with the conventional approach of a larger cable cross-section or a lower fixed switching frequency as a blanket derating margin, the proposed framework achieves compliance without any hardware change, using only drive-side configuration parameters already exposed on commercial drive controllers — of particular value for brownfield sites where re-cabling is costly. The achievable margin is bounded by the parameter ranges in Table I; for conditions far outside those considered here, drive re-tuning

alone may not suffice and physical derating or re-cabling would still be required.

The weighted-sum formulation (Section III-B) is simple to implement, but Section IV shows its outcome depends on the chosen weight vector; the base-case weights [0.5, 0.3, 0.2] reflect a stated industrial priority — cable protection first. Where a different priority applies, Table III can guide the choice among S1–S5, or an alternative scalarization such as ε -constraint or NSGA-II should be considered in place of a single weighted-sum run.

VI. CONCLUSION

This paper presented a PSO-based multi-objective optimization framework for drive parameter tuning that targets the simultaneous minimization of line current, active power consumption, and total harmonic distortion in industrial motor drive systems. The exterior penalty function was shown to be effective in enforcing hard constraints on cable ampacity and harmonic distortion limits, with penalty contributions large and dominant in early PSO iterations and identically zero at the converged optimal solution. MATLAB/Simulink simulation confirmed that the optimized parameter set achieves a 17.6% reduction in effective RMS cable current, a 52.9% reduction in THDI (achieving IEEE 519-2022 compliance), a 36.5% reduction in peak line current, and a 4.8% reduction in total active power. A weight-sensitivity analysis (Section IV) characterized how the base-case weighting compares with alternative priority orderings, and the underlying cable-thermal and harmonic-loss assumptions were justified against established literature formulations. These results indicate that structured, drive-side parameter optimization — rather than conservative rule-of-thumb cable derating alone — can meaningfully improve both the safety and the efficiency of drive-fed motor installations, within the parameter ranges and system configuration considered.

Future work will extend the framework to multi-motor bus configurations, incorporate real-time adaptive re-optimization triggered by load-profile changes, complete the weight-sensitivity runs of Section IV with an explicit Pareto-front comparison, and pursue hardware-in-the-loop validation using a dSPACE or OPAL-RT platform together with field power-quality measurements, so that the switching-loss and cable-heating estimates used in this study can be confirmed against measured data rather than simulation alone. Advanced metaheuristics such as the Grey Wolf Optimizer and Differential Evolution will also be benchmarked against PSO for convergence speed on this problem.

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