Energy and Power 2026, 15(1): 1-3
DOI: 10.5923/j.ep.20261501.01

DC Motor Starting Current

Sarhan Hasan[1,*], Aref M. Alkelani[2], Ahmed Altaher Zuglem[2], Abdelhamid Elgzil[3], Osama Ali Elhenshiri[4], Reda Elbahi[5]

[1]University of Denver, Colorado, USA
[2]Om Alrrabea Faculty of Sciences and Technology, Surman, Libya
[3]University of Colorado at Colorado Springs, USA
[4]Colorado Technical University, USA
[5]Rochester Institute of Technology, USA

Abstract The main purpose of this paper is to determine the behavior of a shunt DC motor during the starting period and to analyze how the motor line current changes compared to its rated current. At the time of starting, the armature of the shunt DC motor is stationary, and no back electromotive force (EMF) is generated to limit the current. Consequently, the motor draws a very high inrush current, often several times greater than its rated current. This study focuses on observing this starting behavior, examining how the current gradually decreases as the motor gains speed and back EMF builds up, and comparing these variations with the rated conditions. The findings aim to highlight the importance of current control methods and protective measures to ensure efficient and safe operation of shunt DC motors.

Keywords DC motor, Starting current, Shunt motor

1. Methodolgy

DC motors can be classified according to the way their field winding is connected to the armature winding. Based on this field connection, DC motors are mainly divided into three types: shunt-wound like in Fig. 1, series-wound, and compound-wound motors. In a shunt DC motor, the field winding is connected in parallel (shunt) with the armature, resulting in nearly constant speed under varying loads because the field current remains almost constant. In a series DC motor, the field winding is connected in series with the armature, so the same current flows through both. This gives the motor high starting torque but causes the speed to vary widely with load, making it suitable for applications like traction or cranes. The compound DC motor combines features of both shunt and series motors by having two field windings—one in series and the other in parallel with the armature—providing a balance between good starting torque and stable speed regulation. Compound motors can be further classified as cumulatively compounded or differentially compounded depending on how the series and shunt fields assist or oppose each other [1].

In a DC motor, although it is supplied with a direct current (DC) source, the current in the armature effectively becomes alternating due to the action of the commutator and stationary brushes. The commutator reverses the direction of current in each armature coil every half rotation, ensuring that the torque always acts in the same direction and the motor continues to rotate smoothly. At the same time, a back electromotive force (back EMF) is generated in the armature as it rotates within the magnetic field. This back EMF gradually builds up as the motor speeds up and opposes the applied voltage, helping to regulate the current flow. Without this back EMF, the armature current would remain excessively high during operation [2]. Torque in a DC motor is produced by the interaction between the magnetic field and the current flowing through the armature conductors. When voltage is applied to the motor, current flows through the armature windings and creates a magnetic field that interacts with the main field flux generated by either permanent magnets or field windings. This interaction generates a force on the conductors, which produces rotational torque on the rotor. At the moment the motor starts, the speed is zero, so no back EMF is generated; as a result, the armature current is at its maximum, giving the motor a high starting torque. As the motor accelerates, back EMF increases and opposes the supply voltage, causing the current to decrease, which in turn reduces the torque. Ultimately, the motor reaches a balance point where the developed torque equals the load torque, and the motor runs at a steady speed. This high initial torque gradually falls as speed builds up — is one of the major advantages of DC motors [3]. In this study, the shunt-type DC motor specifications provided in Table 1 were thoroughly analyzed to develop an accurate representation of the motor's dynamic response, particularly during the transient starting condition.

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* Corresponding author:
sarhanhasan66@yahoo.com (Sarhan Hasan)
Received: Dec. 6, 2025; Accepted: Jan. 2, 2026; Published: Jan. 28, 2026

Table 1. DC motor specifications

V	N rpm	Current (A)	Moment of inertia (J) Kg.m^2	R_aΩ	Back EMF constant (k_e) V.s/rad	Torque constant (k_t) N.m/A
300	4000	15	0.002	2.5	0.6267	0.6267

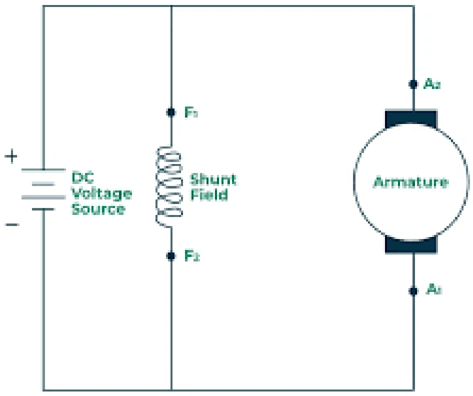

Figure 1. Shunt DC motor [1]

DC motor dynamic equations: [4]

The dynamic behavior of a DC motor during operation can be described using a set of fundamental electromechanical equations. These equations establish the relationships between electrical input, electromagnetic torque generation, and resulting mechanical motion. The torque produced by the motor is directly proportional to the armature current, while the back electromotive force (EMF) is proportional to the rotational speed. By combining the electrical characteristics of the armature circuit with the mechanical dynamics of the rotor, a complete representation of the motor's transient and steady-state performance can be obtained. The governing equations for the DC motor are presented below.

$$T_e = K_t * I_a \tag{1}$$

$$E_b = K_e * w \tag{2}$$

$$I_a = (V_t - E_b)/R_a \tag{3}$$

$$\frac{dw}{dt} = \frac{T_e}{J} \tag{4}$$

Where:

- T: motor torque- N.m
- K_t : torque constant -N.m/A
- I_a: armature current -A
- E_b is back MMF- V
- K_e: Back EMF constant V.s/rad
- W: angular speed in Rad/s
- I_a: armature current A
- V_t: motor terminal voltage-V
- R_a: armature resistance - **Ω**
- J: Moment of Inertia Kg.m^2

Euler's Method:

Euler's Method is a numerical technique for approximating solutions to first-order ordinary differential equations (ODEs) of the form:

$$\frac{dy}{dx} = f(x, y) \tag{5}$$

It is conceptually simple and is often the first numerical ODE method taught.

To approximate the solution curve, Euler's method uses the idea that the slope of the solution at a point (x_n, y_n) is given by the differential equation $f(x_n, y_n)$.

So we take a small step h(step size) in the x-direction and move in the direction of the slope.

$$x_{n+1} = x_n + h \tag{6}$$

$$y_{n+1} = y_n + h\,f(x_n, y_n) \tag{7}$$

The pair (x_{n+1}, y_{n+1}) approximates the true solution at x_{n+1}.

Euler's method is simple, efficient, and easy to implement in real-time simulation codes were written in C language programming for this paper problem topic based on motor dynamic equations 1-4. Table 2 shows and illustrates the applied Euler method equation on DC dynamic equations, and Table 3 shows C codes solution for the same equations.

Table 2. Euler method applications on DC motor dynamic equations

Euler equation	Euler method applied on DC motor dynamic equations
$\frac{dy}{dx} = f(x, y)$	$\frac{dw}{dt} = \frac{T_e}{J}$
$x_{n+1} = x_n + h$	$t = t + h$
$y_{n+1} = y_n + h\,f(x_n, y_n)$	$w = w + h * \frac{dw}{dt}$

Table 3. DC motor dynamic equations solution using C codes by Euler method

```
#include <stdio.h>
#include <stdlib.h>
int main() {
   FILE *fp;
   char line[100];
   fp=fopen("example.csv","w");
   float   W=0.0; float I=120.0; float T; float d; float E;
   for (int i = 1; i <= 400; i++) {
   T=0.627*I;
   d =T/0.002;
   E=0.627*W;
   I=(300-E)/2.5;
   fprintf(fp,"%d    ,    %f,   %f,    %f,    %f\n",i,E,I,W,T);
   W=0.0001*d+W;
   t=t+h;
   }
   fclose(fp);
   return 0;
}
```

2. Results and Discussion

Figure 2 illustrates the exponential decay of the motor's starting current over time. At the moment of startup, the motor experiences a very high inrush current, reaching nearly nine to ten times the rated value—approximately 120 A compared to the nominal 15 A. This surge occurs because the back EMF is initially zero, allowing maximum current to flow through the armature. Although this high current gradually decreases as the motor accelerates, its presence can place significant stress on the winding insulation. Repeated exposure to such large current spikes can lead to excessive heating, insulation degradation, and eventual weakening of the motor's electrical integrity, potentially reducing the motor's lifespan or increasing the likelihood of insulation failure if not properly managed.

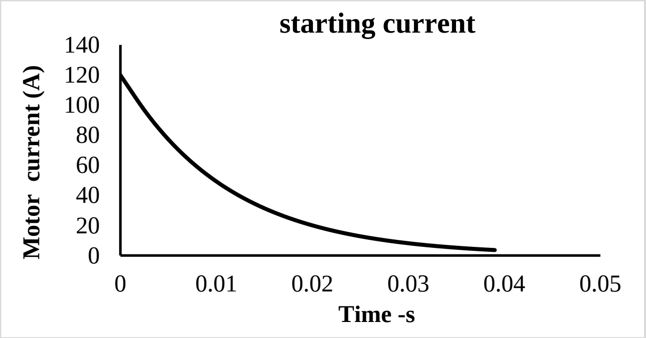

Figure 2. Starting motor current variations

3. Conclusions

The analysis of the shunt DC motor's starting behavior confirms that the motor draws a significantly high inrush current at the moment of startup due to the absence of back electromotive force (EMF). When the armature is stationary, no back EMF is generated to oppose the applied voltage, causing the armature current to reach values several times higher than the rated current. As the motor begins to accelerate, the back EMF gradually increases in proportion to speed, effectively reducing the armature current. This results in a smooth transition from high initial current to the normal operating current once steady-state speed is achieved. Numerical simulation using Euler's method and the motor's dynamic equations validates this characteristic behavior, showing a rapid current drop during the transient period as torque balance is established. The findings highlight the importance of incorporating current-limiting measures—such as starting resistors, soft starters, or electronic drives—to protect the motor against excessive electrical and thermal stress. Ultimately, understanding the starting current profile is essential for ensuring reliable operation, optimizing motor performance, and extending system lifespan.

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