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A Study on the Load Modeling of Railway Vehicles Using PSCAD/EMTDC Based on MVDC

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Abstract: This paper, the kinetic equation, traction force, and braking force for railway trains are reviewed. In addition, the driving characteristics are interpreted as to how the power of the electric vehicle relates to the weight, speed, track curve, and track gradient of the electric vehicle. The driving characteristics of these trains are analyzed through PSCAD/EMTDC (power systems computer aided design/electromagnetic transients including DC) modeling.

Key words: MVDC (medium voltage direct current), railway, load modeling, PSCAD/EMTDC.

1. Introduction

DC-related technologies, such as HVDC (high-voltage direct current) and LVDC (low-voltage direct current), continue to be developed to increase connection capacity and improve efficiency of new and renewable energy. In the future, it is expected to introduce a medium-sized MVDC (medium voltage direct current) distribution network that can link HVDC and LVDC.

Currently, there is no related market in the railway part. However, with the emergence of new MVDC-related equipment, it is expected that the relevant market will soon be formed. The electric railway system is one of the end users who consume a lot of power in KEPCO's power grid. The electric railway system is greatly influenced by the development of MVDC grid technology. As a result, efforts to incorporate applied technologies in the railway sector are expected to lead to an increase in the size of the related market, so it is necessary to model trains for interpretation when applying the MVDC distribution network.

Accurate modeling of the motion and power consumption of railway vehicles is needed. In order to know the exact braking characteristics of the vehicle, based on the relationship between wheel rotation, train traction, and braking [1], Jeon et al. [2] and Kim et al. [3] estimated the traction and braking power for electric locomotives and Korean high-speed trains and compared them with the test results. Choi et al. [4] derived and tested acceleration changes for HEMU-430X, a high-speed train that is a power-distributed train, and Kim et al. [5] presented maximum acceleration values and specifications when implementing high-performance cars for next-generation trains. Therefore, in this paper, the kinetic equation, traction force, and braking force for railway trains are reviewed. In addition, the driving characteristics are interpreted as to how the power of the electric vehicle relates to the weight, speed, track curve, and track gradient of the electric vehicle. The driving characteristics of these trains are analyzed through PSCAD/EMTDC modeling.

2. Train Operation Relationship Formula

The electric railway system is a vast system that includes a number of train groups and operations, tracks, and electrical installations. In order to perform the

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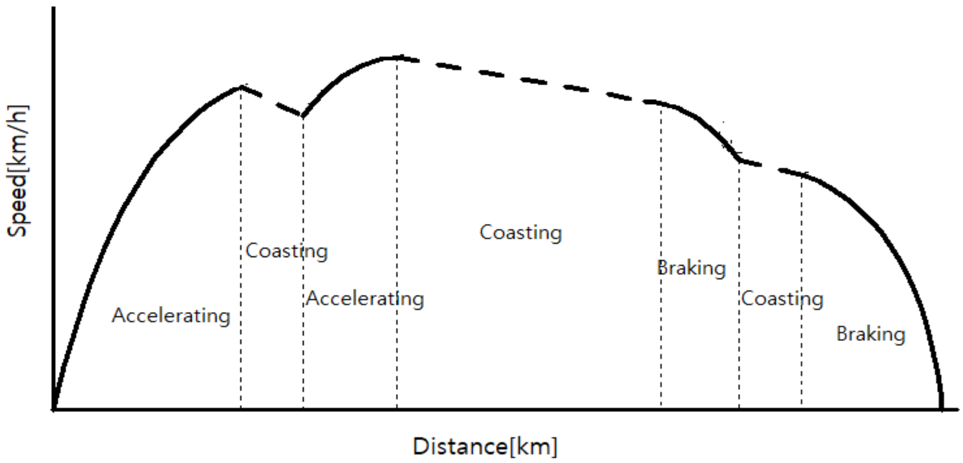

Fig. 1 Standard operation curve.

simulation, numerous input data and conditions must be set. Most railway vehicles maintain a simple pattern of starting-accelerating-coasting-braking-stop and operate on the basis of the standard driving curve shown in Fig. 1. The electric vehicle generates reverse and regenerative currents according to speed and position. The railway vehicle obtains acceleration and deceleration to determine the following driving conditions and speeds. Therefore, the railway vehicle has one of the operation modes shown in Fig. 1. That is, the next position is determined according to the speed of the electric vehicle. When the speed and position are determined, the operation mode is determined according to the standard operation curve [6-8].

The basic formulas for train operation are as shown in Eqs. (1) and (2).

$$v = \frac{ds}{dt} \tag{1}$$

where,

v: speed (km/h)

s: distance (m)

t: time (s)

$$a = \frac{dv}{dt} \tag{2}$$

where, a: acceleration(km/h/s).

Eqs. (1) and (2) represent relational equations for position, speed, and acceleration in linear motion. When the acceleration is constant, the function $v(t)$ of the velocity with respect to time and the function $x(t)$ of the distance are as shown in Eqs. (3) and (4).

$$v(t) = v_0 + at \tag{3}$$

$$v(t) = \frac{1}{2}at^2 + v_0 t + S_0 \tag{4}$$

The acceleration a train can produce is related to the traction force of the motor and the resistance of the train. The acceleration of the train is the value obtained by dividing the effective traction by the dynamic mass, as shown in Eq. (5).

$$a = \frac{F_{\text{eff}}}{m_{\text{dyn}}} \tag{5}$$

where,

F_{eff}: effective traction (kN)

M_{dyn}: dynamic mass (ton)

The dynamic mass includes the dynamic mass in the full vehicle mass, which takes into account the force required by rotating the wheels of the train as well as linear motion.

The dynamic mass is obtained by multiplying the M-car by the compensation coefficient of 0.14 and the T difference by the compensation coefficient of 0.06.

$$M_{\text{dyn}} = 0.14 \times M_{\text{m}} + 0.06 \times M_{\text{t}} \tag{6}$$

where,

M_{dyn}: dynamic mass (ton)

M_{m}: M-Car overall tolerance weight (ton)

M_{t}: T-Car overall tolerance weight (ton)

0.14: M-Car inertial mass compensation factor

0.06: T-Car inertial mass compensation factor

The effective traction force is the value obtained by subtracting the train resistance from the motor traction force, as shown in Eq. (7).

$$F_{\text{eff}} = F_{\text{mtf}} - R \tag{7}$$

where,

F_{eff}: effective traction (kN)

F_{mtf}: electric traction (kN)

R: train resistance (kN)

In this case, the train resistance R is the sum of the curve resistance, the running resistance, and the gradient resistance, and is expressed as Eq. (7), and the resistance is as shown in Eq. (8).

$$R = R_{\text{curve}} + R_{\text{run}} + R_{\text{gradient}} \tag{8}$$

where,

R_{curve}: curve resistance (kN)

R_{run}: running resistance (kN)

R_{gradient}: gradient resistance (kN)

Curve resistance

$$R_{\text{curve}} = \frac{700\times W_{\text{full}}}{r} \times 9.8 \times 10^{-3}\ \text{(kN)} \tag{9}$$

where,

R_{curve}: curve resistance (kN)

W_{full}: full load weight (ton)

r: curved radius (m)

Running resistance

$$-R_{\text{run}} = 1.867 + 0.0359V + 0.000745V^2\ \text{(kgf/ton)} \tag{10}$$

where,

V: vehicle speed (km/h)

Gradient resistance

$$R_{\text{gradient}} = G \times W_{\text{full}} \times 9.8 \times 10^{-3}\ \text{(kN)} \tag{11}$$

where,

R_{gradient}: gradient resistance (kN)

W_{full}: full load weight (ton)

G: gradient (‰)

3. Traction and Braking Forces

The traction force and braking force are calculated by applying the following formula.

$$F\ \text{(N)} = m\ \text{(kg)} \times a\ \text{(m/s}^2) + r\ \text{(N)} \tag{12}$$

In the above equation, the units are converted into (kN) and (ton) as follows.

$$F\ \text{(kN)} = M\ \text{(ton)} \times a\ \text{(m/s}^2) + R\ \text{(kN)} \tag{13}$$

where,

M: Train full weight including inertial mass (ton) ($M = W_{\text{full}} + M_{\text{dyn}}$)

W_{full}: load weight (ton)

M_{dyn}: dynamic mass (ton)

R: train resistance (kN)

The railway vehicle travels at the same acceleration up to 35 km/h as shown in Fig. 2, subsequently the acceleration decreases and the speed increases at full speed.

The measurement data of the next-generation electric vehicle developed by the Korea Railroad Research Institute were compared with the simulation. Fig. 3 is the measurement data related to traction over time, and it was found that the train performs uniformally accelerated motion up to 35 km/h. It can be seen that the speed increases to the maximum speed as the acceleration decreases after 35 km/h.

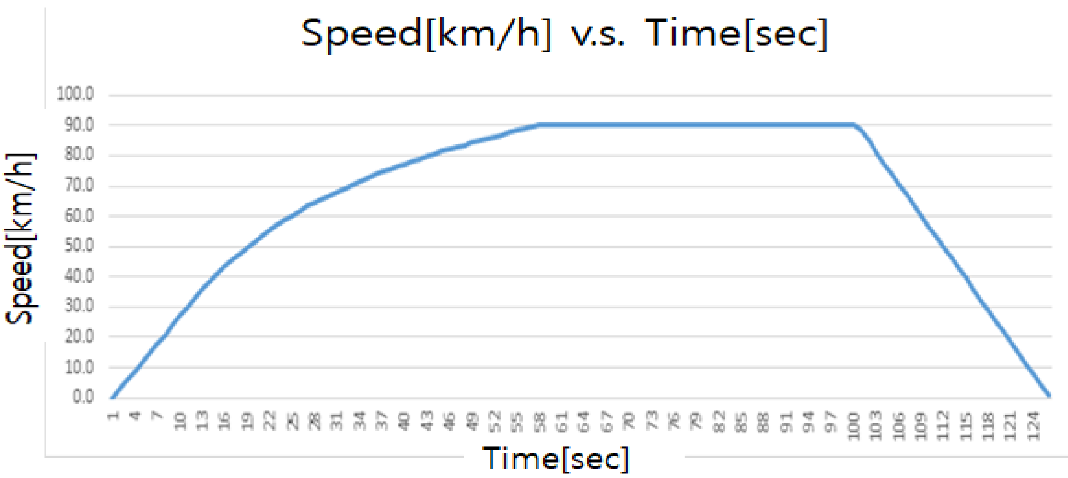

Fig. 2 Speed curve over time.

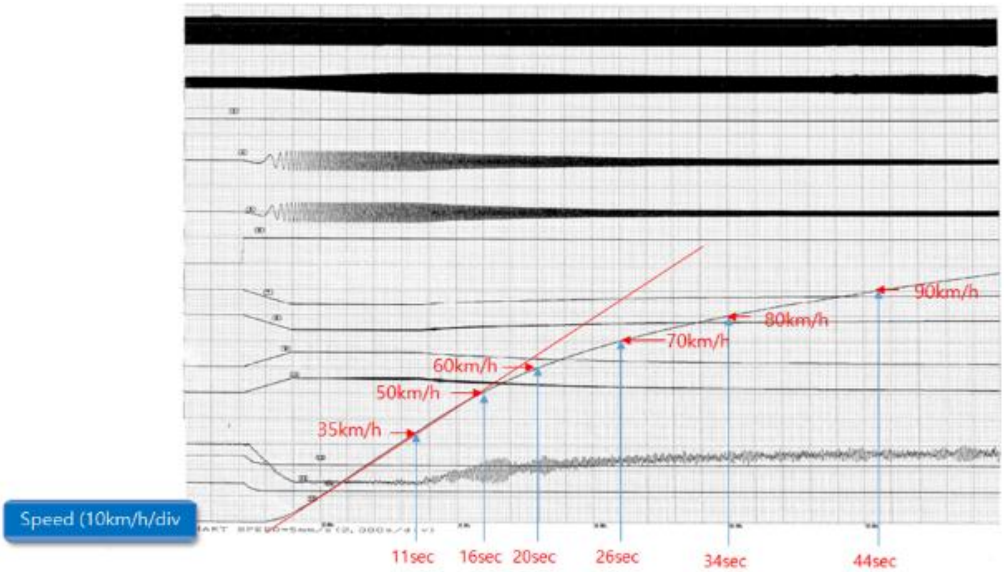

Fig. 3 **Measurement data related to traction over time.**

Fig. 4 **Simulation data related to traction over time.**

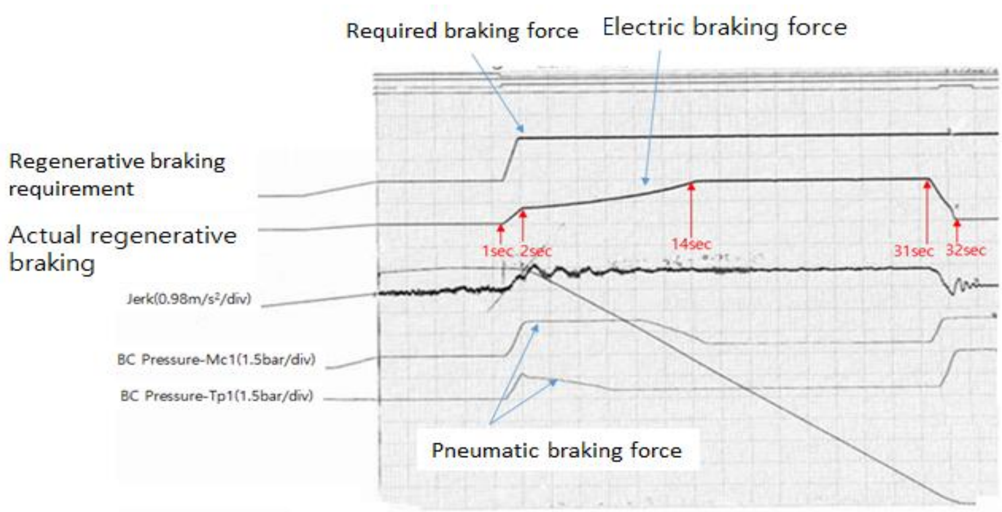

Fig. 5 **Measurement data related to braking force over time.**

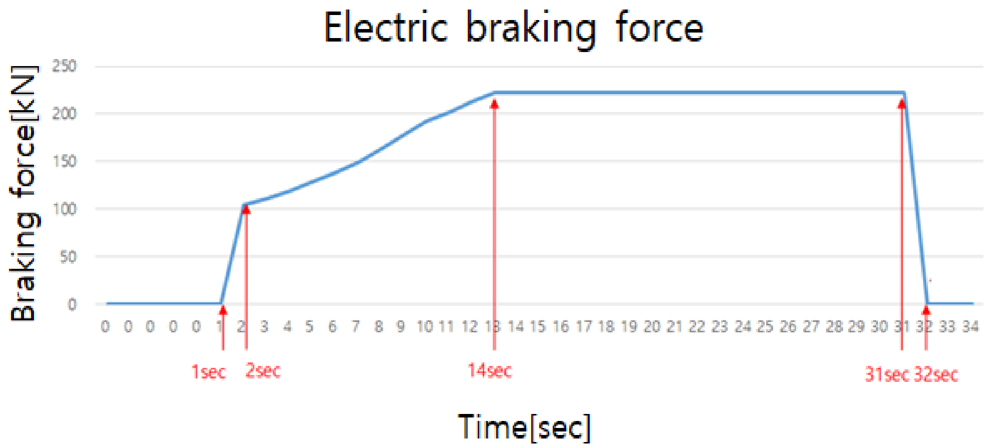

Fig. 6 Simulation data related to braking force over time.

Fig. 4 is the result of the simulation of traction over time, and as a result of comparing the simulation data related to traction with the measurement data, the corresponding time for each speed was the same.

Fig. 5 shows the measurement data for braking force over time, and the electric braking power reached the maximum in 14 seconds. Fig. 6 is the result of simulating the braking force over time. In the same way as the measurement data, the braking force was maximized at 14 seconds. Therefore, as a result of comparing the braking force-related simulation data with the measurement data, the corresponding time for each speed was the same.

4. Modeling and Analysis of Constant Power Vehicles Based on Driving Characteristics

The vehicle model has been modeled based on the driving characteristics described earlier. The vehicle has been implemented using PSCAD/EMTDC as a current source reflecting the vehicle's driving characteristics as shown in Fig. 7.

Various vehicle modes of operation can be implemented. The speed curves according to traction, coasting and braking operation modes are shown in Fig. 8. The traction and braking forces are shown in Figs. 9 and 10, respectively.

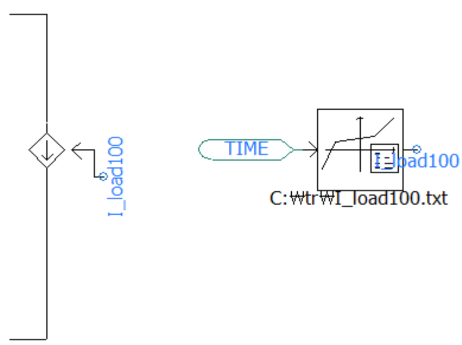

Fig. 7 Constant power load modeling.

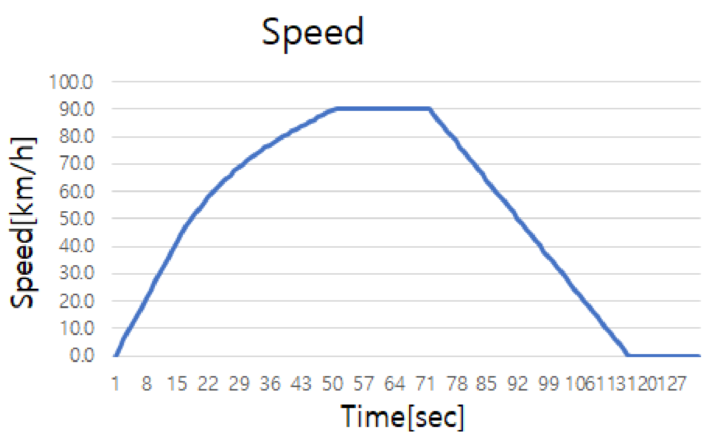

Fig. 8 Operation Mode accelerating-costing-breaking.

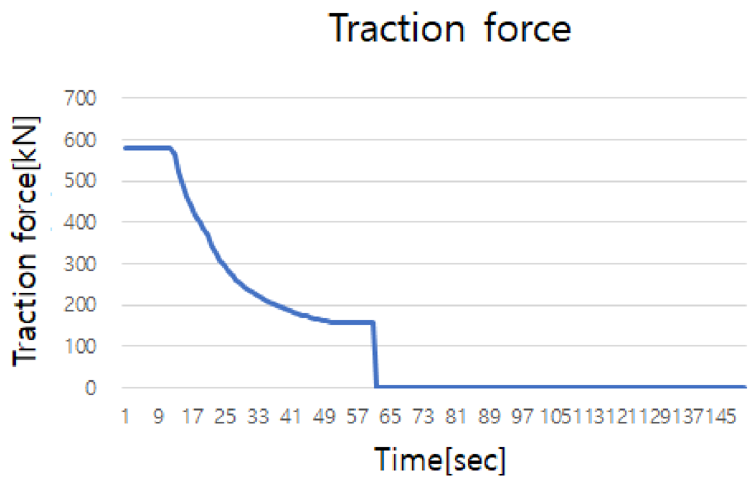

Fig. 9 Traction force according to operation mode.

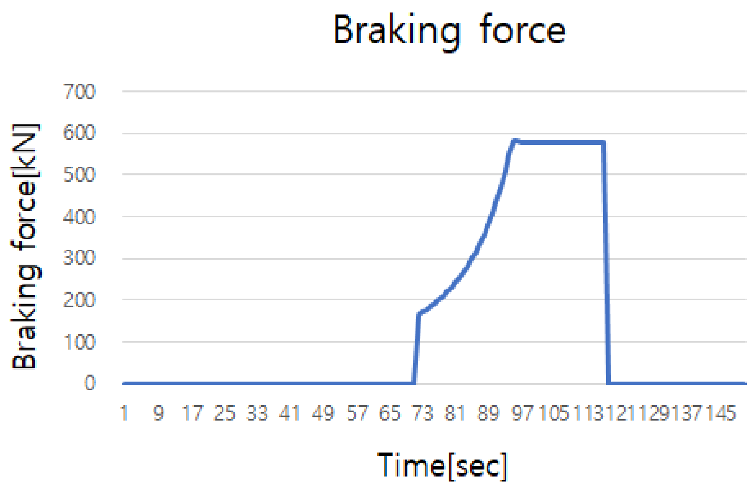

Fig. 10 Braking force according to operation mode.

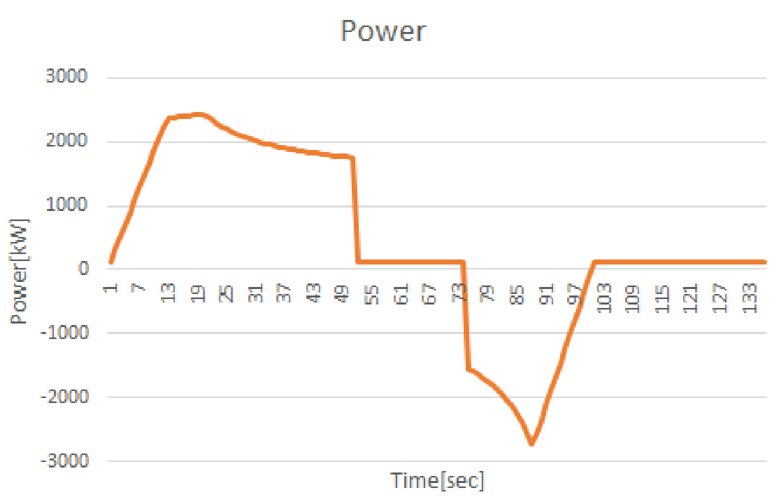

Fig. 11 Traction power and regenerative power according to the operation mode.

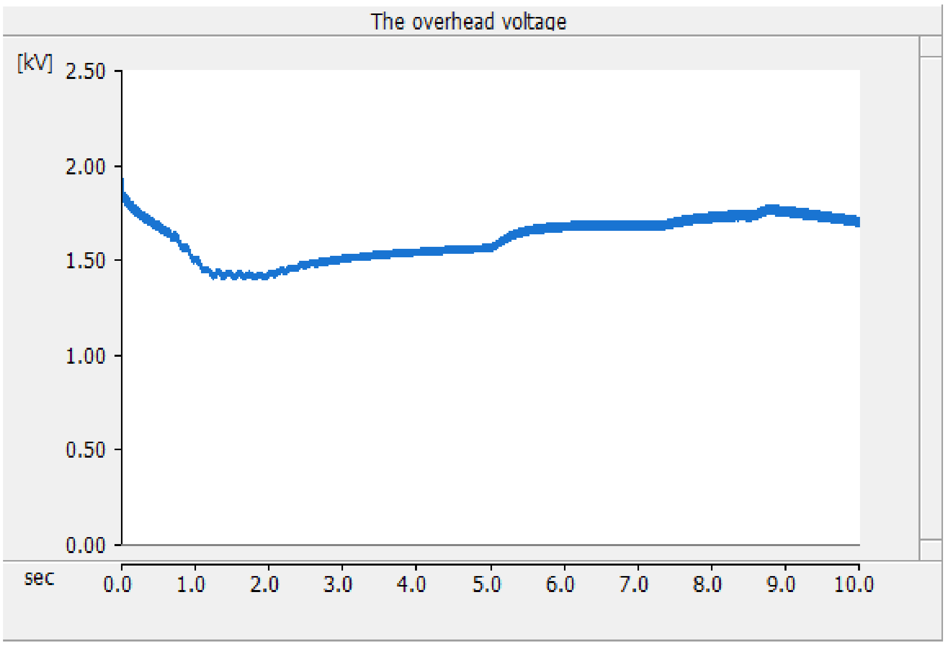

Fig. 12 Catenary voltage.

Fig. 11 shows the traction power and regenerative power according to the operation mode of Fig. 8, and Fig. 12 shows the catenary voltage, and it can be seen that the voltage drops below 1.5 kV when the vehicle is towed and rises to 1.5 kV or more when regenerating.

5. Conclusion

In this paper, the equations of motion, traction and braking of the vehicle were reviewed. In addition, the driving characteristics are interpreted as to how the power of the electric vehicle relates to the weight, speed, track curve, and track gradient of the electric vehicle. The driving characteristics of these trains are analyzed through PSCAD/EMTDC modeling.

Simulation results and measurement data for traction and braking over time were compared. As a result, simulation data and measurement data showed the same time for each speed. The results showed that the vehicle model was properly implemented with PSCAD/EMTDC.

Acknowledgments

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