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PERFORMANCE AND ANALYSIS OF FOUR SWITCH THREE PHASE INVERTER CONTROL FOR BLDC MOTOR USING MATLAB

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Abstract: The main objective of this paper is to describe a low cost four-switch brushless dc (BLDC) motor drive for commercial applications. Speed control of three phase BLDC motor using four switch inverter is proposed to simplify the structure of the conventional six switch inverter. For effective utilization of the developed system, a novel direct current controlled PWM scheme is designed and implemented to produce the desired dynamic and static speed–torque characteristics. PI controller is used by the outer loop to develop the performance of speed control. The operational principle of the four-switch BLDC motor drive and the developed control scheme are theoretically analyzed and the performance is demonstrated by both simulation and experimental results in MATLAB.

Keywords: BLDC motor, Four-switch three phase inverter

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INTRODUCTION

The adjustable-speed drive is preferred over a fixed speed motor due to energy saving, velocity or position control and amelioration of transients. The purpose of a motor speed controller is to take a signal representing the demanded speed and to drive the motor at that speed. [10] Brushless DC motors are mostly preferred because they offer several advantages, including long lifetime, reduced noise and good weight/size to power ratio. Brushless DC motors are used in a growing number of applications such as computer hard drives, CD/DVD players and PC cooling fans. Low speed, low power brushless DC motors are used in direct- drive turntables for analog audio records. High power BLDC motors are found in electric vehicles, hybrid vehicles and some industrial machinery. The cost reduction of variable-speed drives is accomplished by two approaches. One is the topological approach and the other is the control approach. From a topology point of view, minimum number of switches is required for the converter circuit. In the control approach, algorithms are designed and implemented in conjunction with a reduced component converter to produce the desired speed–torque characteristics. As a result, many different converter topologies have been developed and various PWM control strategies have been proposed to enhance the performance of the system. [11] A conventional BLDC motor drive is generally implemented via a six switch, three-phase inverter and three Hall-effect position sensors that provide six commutation points for each electrical cycle. Cost minimization is the key factor in an especially fractional horse-power BLDC motor drive for home applications. It is usually achieved by elimination of the drive components such as power Switches and sensors. Therefore, effective algorithms should be designed for the desired performance. Recently, a four switch, three-phase inverter (FSTPI) topology has been developed and used for a three-phase BLDC motor drive. Reduction in the number of power switches, dc power supplies, switching driver circuits, losses and total price are the main features of this topology. It results in the possibility of the four-switch configuration instead of the six switches. Compared with the four switch converter for the induction motor, it is identical for the topology point of view. However, in the four-switch converter, the generation conducting current profiles is inherently difficult due of 120° to its limited voltage vectors. This problem is well known as "asymmetric voltage PWM." It means that conventional PWM schemes for the four-switch induction motor drive cannot be directly used for the BLDC motor drive. Therefore, in order to use the four-switch converter topology for the three-phase BLDC motor drive, a new control scheme should be developed. The solutions can be obtained from a modification of the conventional voltage controlled PWM strategies, such as the space vector PWM. However, it naturally requires lots of equations for the transformation of voltage and current vectors, α-β and a–b–c frames. As a result, the current control such as block becomes much more complicated. Moreover, in order to handle the complicated calculations in one sampling period, a high-speed digital processor is also necessary, which increases the manufacturing cost. Therefore, for the low cost BLDC motor applications, voltage vector PWM schemes cannot be regarded as a good solution for cost effective purpose. Modeling and simulation of electromechanical systems with BLDC drives are essential steps at the design stage of such systems. For the purposes of stability analysis and controller design it is often desirable to investigate the large-signal transients and small-signal characteristics of the system. Simulation studies are also often performed many times to achieve the required design goals. In this study, the nonlinear simulation model of the BLDC motors drive system with proportional-integral (PI) control based on MATLAB/Simulink platform is presented.

CONVENTIONAL METHOD FOR SPEED CONTROL OF BLDC MOTOR

Commutation ensures proper rotor rotation of the BLDC motor, while the motor speed depends only on the amplitude of the applied voltage. The amplitude of the applied voltage is adjusted by using the PWM technique. The required speed is controlled by a speed controller. The speed controller is implemented as a conventional PI controller. The difference between the actual and required speed is input to the PI controller and based on this difference, the PI controller controls the duty cycle of PWM pulses, which corresponds to the voltage amplitude required to keep the required speed.

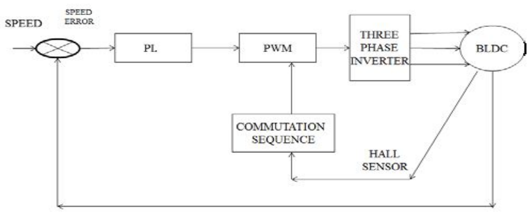

Fig 1. Conventional block diagram for Speed control of BLDC motor

The speed controller calculates a Proportional-Integral algorithm according to the following equation is $u(t) = k_c e(t) + \frac{1}{T1}\int_0^t e(t)\,dt$ (9)

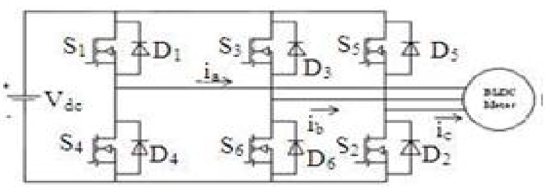

Fig 2.Conventional six-switch inverter used for BLDC motor

illustrated in fig 2. The power stage utilizes six power transistors with switching in either the independent mode or complementary mode. In both mode, the 3-phase power stage energizes two motor phases concurrently. The third phase is unpowered. Thus, six possible voltage vectors are applied to the BLDC motor using a PWM technique. There are two basic types of power transistor switching, independent switching and complementary switching, which are discussed in the following sections. Fig. 3 shows the configuration of a four-switch inverter for the three-phase BLDC motor. It has two common capacitors, instead of a pair of bridges are used and phase c is out of control because it is connected to the midpoint of the series capacitors. From fig. 2, the phase current cannot hold at zero and it causes an additional and unexpected current, resulting in current distortion in phases a and b and even in the breakdown of the system. The same problem is inherited by the four-switch mode and it causes the produced voltage vectors to be limited and asymmetric, which were well known as asymmetric voltage vectors. In Table 1 show the basic operating principle of BLDC.

II. DESCRIPTION OF PMBLDCM DRIVE

Commutation ensures proper rotor rotation of the BLDC motor, while the motor speed depends only on the amplitude of the applied voltage. Fig.2 describes the basic building blocks of the PM BLDC motor drive. The drive consists of speed controller, reference current generator, pulse width modulation (PWM) current controller, position sensor, the motor and a IGBT based voltage source inverter (CC-VSI). The speed of the motor is compared with its reference value and the speed error is processed in PI speed controller. The output of this controller is considered as the reference torque. A limit is put on the speed controller output depending on permissible maximum winding currents. The reference current generator block generates the three phase reference currents (ia*, ib*, ic*) using the limited peak current.

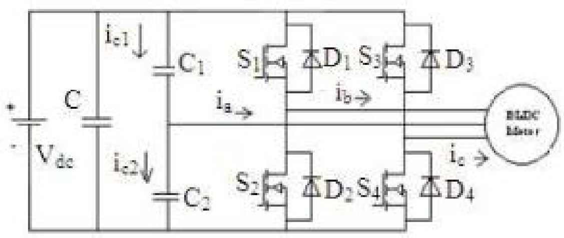

Fig. 3 Configuration of four-switch three-phase inverter

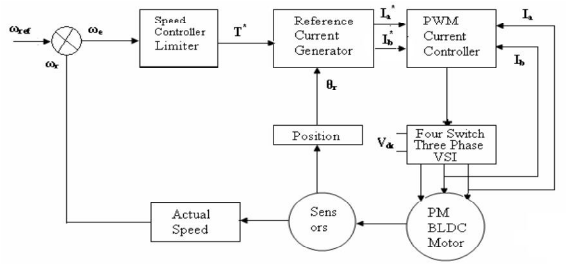

Fig.4 PI-Speed Controller

The PI controller is widely used in industry due to its ease in design and simple structure. The rotor speed ωr(n) is compared with the reference speed ωr(n)* and the resulting error is estimated at the nth sampling instant as:

$$\omega(n) = \omega(n)^* - \omega(n) \qquad (1)$$

The new value of torque reference is given by

$$T(n) = T(n-1) + K_P \omega e(n) - \omega e(n-1) + K_1 \omega e(n) \quad (2)$$

Where 'ωe(n − 1)' is the speed error of previous interval, and 'ωe(n)' is the speed error of the working interval. KP and KI are the gains of proportional and integral controllers respectively. By using Ziegler Nichols method the K_P and K_I values are determined [10]

REFERENCE CURRENT GENERATOR:

Unlike a brushed DC motor, the commutation of a BLDC motor is controlled electronically. To rotate the BLDC motor, the stator windings should be energized in a sequence. Most of BLDC motors have three Hall sensors embedded into the stator on the non-driving end of the motor. Rotor position is sensed by Hall Effect sensors embedded into the stator which gives the sequence of phases. Whenever the rotor magnetic poles pass near the Hall sensors, they give a high/low signal, indicating the N or S pole is passing near the sensors. Based on the combination of these three Hall sensor signals, the exact sequence of commutation can be determined. The magnitude of the reference current (I∗) is determined by using reference torque (T∗) and the back emf constant (K_b) $I* = \frac{T*}{KB}$ Depending on the rotor position, the reference current generator block generates three-phase reference currents (ia∗, ib∗, ic∗)

considering the value of reference current magnitude as I∗, − I∗ and zero. The reference current generation is shown in Fig.4

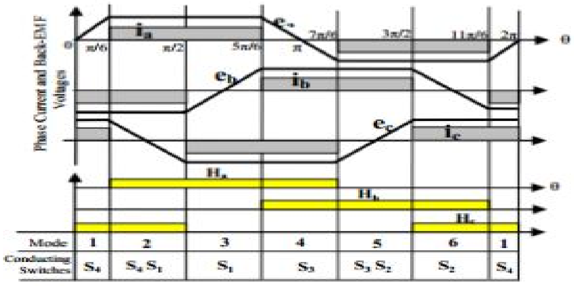

Fig.5 Back EMF, current profile, modes, conducting switches in the four-switch converter for three-phase BLDC motor drives

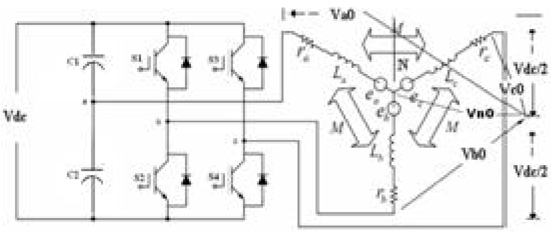

Fig.6 Inverter circuit with BLDC Motor drive

Terminal voltages of a BLDC motor in the four switch inverter with respect to the mid-point of the dc bus are as follows:

$$V_{ao} = Ri_a + L\frac{di_a}{dt} + e_a + V_{no} \quad (3)$$

$$V_{bo} = Ri_b + L\frac{di_b}{dt} + e_b + V_{no} \quad (4)$$

$$V_{co} = Ri_c + L\frac{di_c}{dt} + e_c + V_{no} \quad (5)$$

III. OPERATIONAL PRINCIPLE OF

DIRECT CURRENT CONTROLLED PWM

From the motor point of view, even though the BLDC motor is supplied by the four-switch converter, ideal back-EMF of three-phase BLDC motor and the desired current profiles can be described as shown in Fig. 5. From the detailed investigation of the four-switch configuration and back-EMF and current profiles, we could come up with a PWM control strategy for the four-switch three-phase BLDC motor drives as follows: Under a balanced condition, the three-phase currents always satisfy the following condition.

$$I_a + I_b + I_c = 0 \qquad (6)$$

Then, (1) can be modified as

$$I_c = -(I_a + I_b) \qquad (7)$$

In the case of the ac induction motor drive, at any instant there are always three phase currents flowing through the load, such as

Ia≠0; Ib≠0; Ic≠0 (8)

However, in the case of the BLDC motor drive, (3) is not valid anymore. Note that in Fig. 5. phase A and B currents are only controllable and phase C is uncontrollable. According to the operating modes, one can derive the following current equations: Table I implies that due to the characteristics of the BLDC motor, such as two-phase, only two phases (four switches) needed to be controlled, not three phases. Therefore, based on Table I, one can develop a switching sequence using four switches as follows:

Table 1.Rotor position signal Vs reference current

Rotor Position Signal θ_r	Reference Currents (i_a*, i_b *, i_c *)		
330°-0° to 0°-	0	–I *	I*
30° - 90°	I	–I	0
90° -150°	I	0	–I
150° - 210°	0	I*	–I
210° - 270°	–I	I*	0
270° - 330°	–I	0	I*

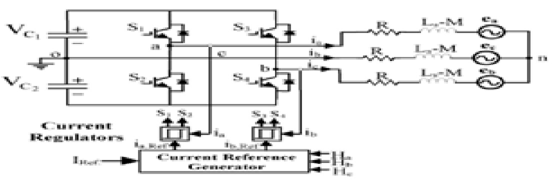

Fig. 6 Proposed four-switch converter topology for three-phase BLDC motor

As shown in Table II, the two-phase currents need to be directly controlled using the hysteresis current control method by four switches. Hence, it is called the direct current controlled PWM scheme. Based on the direct current controlled PWM, implementation of the switching sequence and current flow are depicted in Fig. 6.

Table 2. Switching Sequence of Four switch BLDC motor

MODES	ACTIVE PHASES	SILENT PHASES	SWITCHING DEVICES
Mode 1	Phase B and C	Phase A	S4
Mode 2	Phase A and B	Phase C	S1 and S4
Mode 3	Phase A and C	Phase B	S1
Mode 4	Phase B and C	Phase A	S3
Mode 5	Phase A and B	Phase C	S2 and S3
Mode 6	Phase A and C	Phase B	S2

As shown in Table II, the two-phase currents need to be directly controlled using the hysteresis current

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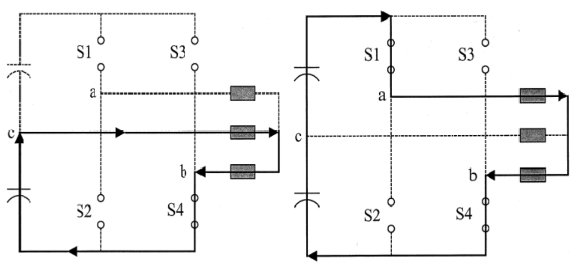
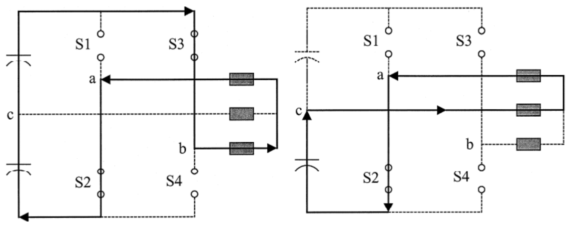
(a) (b)



(c) (d)



(e) (f)

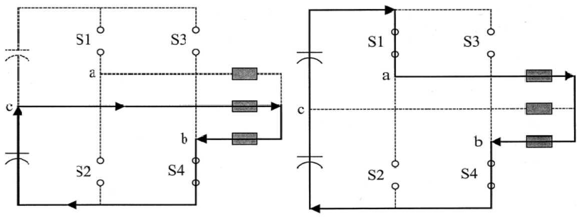


Fig. 7 Implementation of the direct current controlled pwm strategy. (a) ModeI (S4). (b) Mode II (S1 and S4). (c) Mode III (S1). (d) Mode IV (S3). (e) Mode V (S3 and S2). (f) Mode VI (S2).

CURRENT REGULATION

Based on the switching sequences in Table II, the current regulation is actually performed by using hysteresis current control. The purpose of regulation is to shape quasisquare waveform with acceptable switching (ripple) band. The detailed waveforms and switching sequences are described in Fig. 9 The bold line is the current reference value, which is obtained from the torque and speed control loop to achieve the reference torque. The switching frequency and torque ripple are the main considerations for setting the upper and lower limits. It means that a smaller band causes higher switching frequency, but lower torque ripple. Using mode II and mode III, the current regulation can be explained as follows: In mode II,Ia and Ib currents (Ia>0 ,Ib<0) flow and Ic=0. Therefore, mode II is divided into two cases, such as dia/dt>0,dib/dt<0 and dia/dt<0,dib/dt>0. In this mode, as shown in Fig. 6(b), switches S1and S5 are used. Until Ia(Ib) reaches the upper (lower) limit, S1 and S4 are turned on for supplying dc-link energy to increase the current.When the current reaches to the upper limit, S1and S4 are turned off to decrease the current through the anti-parallel diodes D2 and D3. At that time, the reverse bias (negative dc-link voltage) is applied to the phases, resulting in decreasing the current. On the other hand, in mode III, only one current (Ia) can be controllable. It means that only switch S1 can be used as shown in Fig. 6(c). However, the same principle as used for mode II is applied to mode III. When Ia increases,S1 is turned on and other case S1 is turned off.

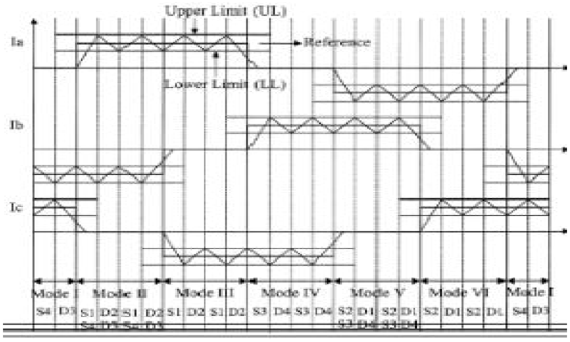


Fig.8 Current regulation and detailed switching sequences.

IV. SIMULATION RESULTS

In this work the drive model with PI speed controller is developed and simulated in order to validate the four switch three phase inverter control of BLDC motor model and the designed controller. For conducting the studies and analysis, this paper considers a typical BLDC motor with importance specification Rated power = 1.03 Kw Pole = 4 R_s= 18.7 K_t = 1.0302 K_i = 0.008 Fig.9-12 shows simulated results with settling time is 0.5 sec.

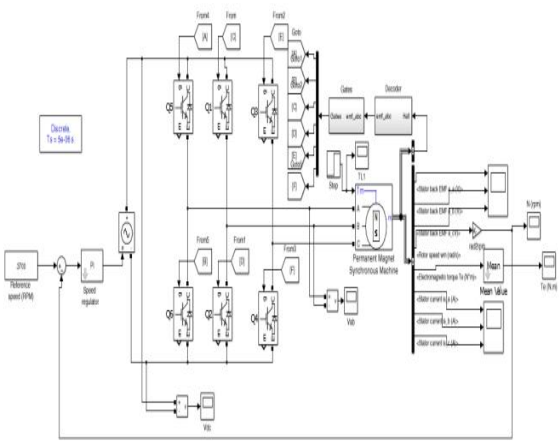


Fig:9 Simulink model of closed loop BLDC motor feed by three phase Six switch Inverter

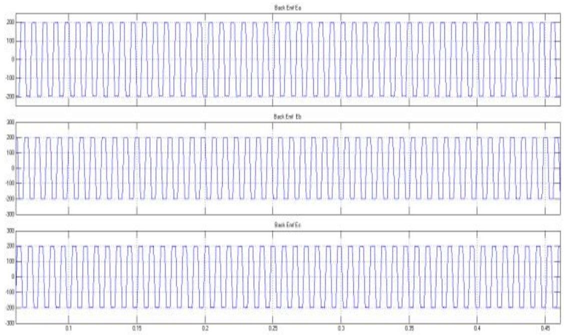


Fig 10 (a) Trapezoidal back EMF

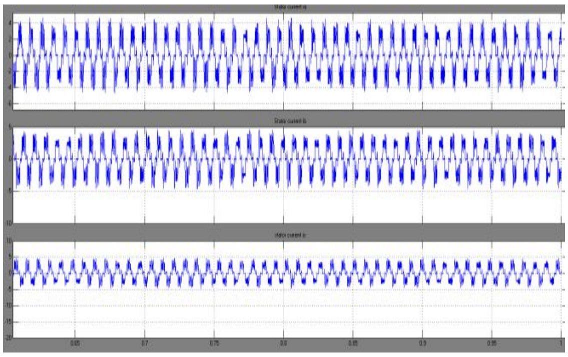


Fig 10 (b) Stator current

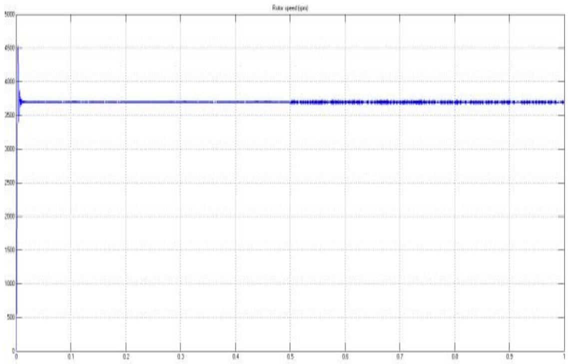


Fig 10 (c) Control rotor speed in rpm

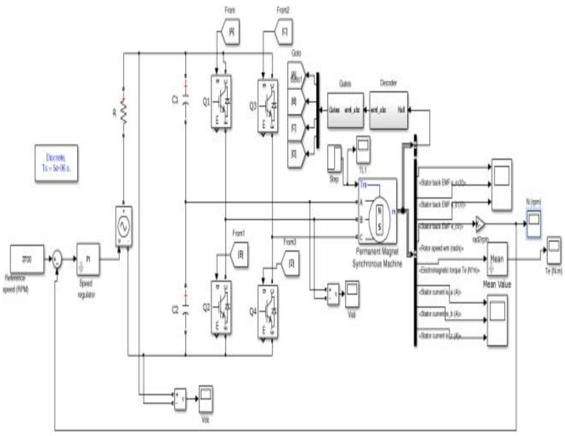


Fig. 10 Simulink model of closed loop BLDC motor feed by three phase Four switch Inverter

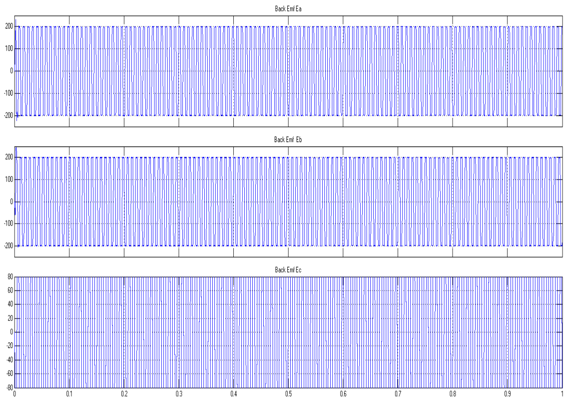


Fig 11 (a) Trapezoidal back EMF

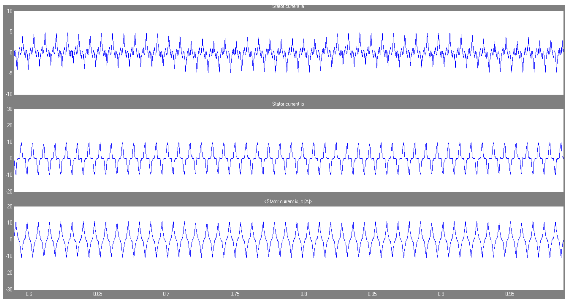


Fig 11 (b) Stator current

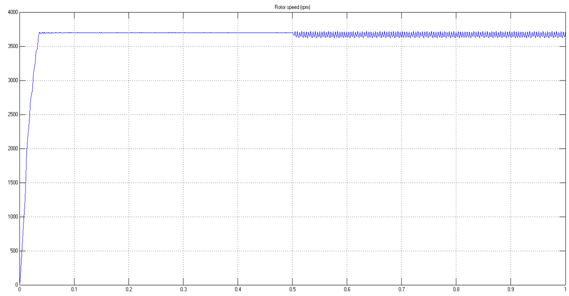


Fig 11 (c) Control rotor speed in rpm

Conclusion: The simulation model of the BLDC motors drive system with PI control based four switch three phase inverter on MATLAB/Simulink platform is presented to provide a possibility for the realization of low cost and high performance three-phase BLDC motor drive system. From the observation, one should note that the development of the proper pwm control strategy should be accompanied with the reduced parts converter. As a solution, we propose the direct current controlled pwm and examine the performance. With the developed control scheme, it is expected that the proposed system can be widely used in commercial applications with a reduced system cost.

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