A Study on Energy Usage Efficiency Improvement Scheme in 48V Multi-axis Robot System

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***Abstract*—Generally, regeneration occurs in an AC variable frequency drive system when the load overhauls the motor. In this paper, it is proposed the scheme of energy efficiency improvement in 48V multi-axis robot system with a frequently accelerating and decelerating operation patterns that can cost-effectively use the regeneration energy and also minimize DB from the system. As a result, it is shown that the proposed method is used to develop the extra power from the expanded regeneration section over the conventional method and the effectiveness is proved thorough the developed topology of FCC and experiment result.**

***Index Terms*—energy regeneration, energy efficiency, multi-axis robot, forward choke converter (FCC), 48V servo system**

I. Introduction

Energy costs and environmental concerns are placing greater importance on variable frequency drive systems in general. The importance of options for increased energy efficiency and over voltage recovery is increasing as well. The potential for recovery of energy from existing and new drive systems is vast, and provides the dual benefit of conserving energy and reducing environmental impact in a wide array of applications.

Generally, regeneration occurs in an AC variable frequency drive system when the load overhauls the motor. When the rotor of a motor turns slower than the speed set by the applied frequency, the motor is transforming electrical energy into mechanical energy at the motor shaft. The process is referred to as motoring. When the rotor turns faster than the synchronous speed set by a drive output, the motor is transforming mechanical energy from the motor shaft into electrical energy.This condition is referred to as regeneration [1], [2].

Essentially, mechanical energy is converted to electrical energy. The converted energy flows into the drive and increases DC bus voltage in the inverter. Some drives have not only a forward but also a reverse bridge. The reverse bridge allows the DC energy to be transferred to the utility line. If the DC drive has only the forward bridge, a shunt regulator can be used in parallel with DC bus link to dissipate the energy into heat.

If the motor is regenerating, the DC bus voltage will increase. So unless a method of dealing with the regenerative energy is provided, the drive will protect itself with a bus overvoltage trip, thus stopping the regenerative condition [3], [4].

The related papers are proposed to explain how to deal with the regeneration energy in industrial sector. Nick Papanikolaou [5] shows an theoretical and experimental investigation of brake energy recovery in industrial loads. In this paper, the result shows that energy recovery may vary at a stationary level but require the proper design of the circuitry. In the aspect of the topology and the regeneration method, there is a difference between paper [5] and the proposed paper.

In general, there are three case to handle this energy as shown in Fig. 1.

Case 1) Use ‘dynamic braking’ to dissipate the energy into heat.

Dynamic Braking (DB) is typically used for applications that require frequent or rapid braking, especially of high inertia loads. However, many such applications could also be candidates for regenerative converters. But the waste heat generated by DB often creates the need for additional cooling and air-conditioning.

Case 2) Use ‘regenerative converter’ to transfer the extra energy to grid.

A regenerative unit will save the extra energy and cost by eliminating that waste heat and returning the energy back to the AC line. However, the conventional regenerative converter has the feature that the regeneration mode starts when the over voltage level is

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met to the regeneration voltage level that depends on the system. Therefore, there in no action of saving extra energy in the DC bus under the normal level between the regeneration voltage level and the initial charging voltage level.

Case 3) Use ‘Several drives and tie the DC bus connections together.

The regenerative energy from one motor can be absorbed and used by another motoring drive on the same DC bus line. However, this method is needed to synchronize the regeneration time and the motoring time in the system.

In this paper, it is proposed the scheme of energy efficiency improvement in 48V multi-axis robot system with a frequently accelerating and decelerating operation patterns that can cost-effectively use the regeneration energy and also minimize DB from the system as shown in Fig. 2.

This method uses the over voltage between the regulated charging voltage from the AC line and the any voltage levels at regeneration condition to convert the regenerative power to 24V dc power that using the dc/dc converter instead of adapting electric components for returning the energy back to the AC line.

In addition, the developed 24V regeneration power is combined with the internal 24V SMPS to supply the hybrid 24V dc power for the total system.

II. Proposed Method

As a general rule, DB can be used when the need to dissipate regenerative energy is on occasional or periodic basis. But the multi-axis robot systems are needed to adapt the newly, cost-effective and different energy saving scheme because of repeating the periodic operation pattern of acceleration and deceleration under the short task run time.

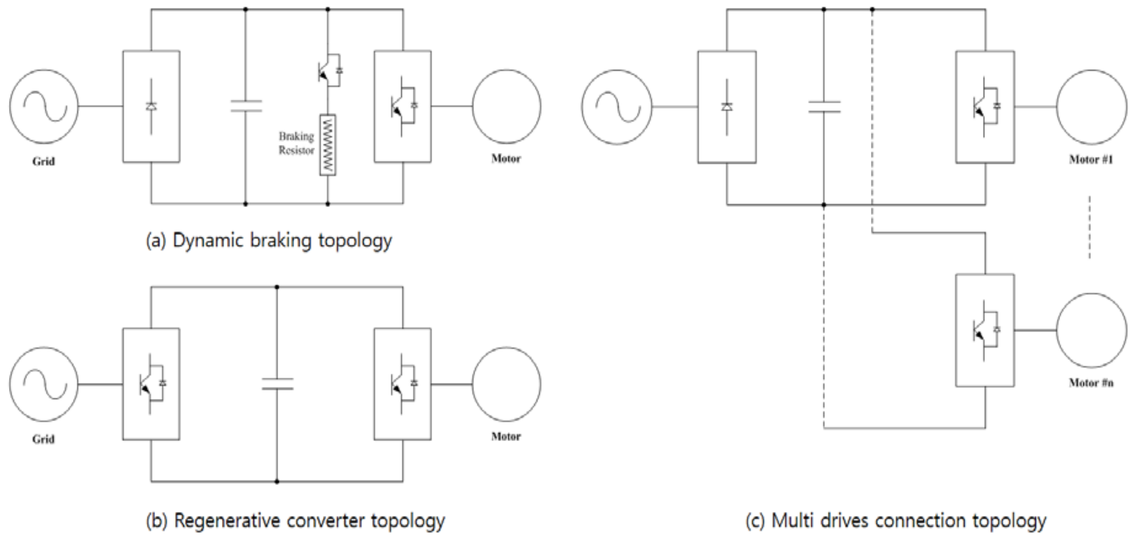

Figure 1. Conventional topology for handling energy regeneration

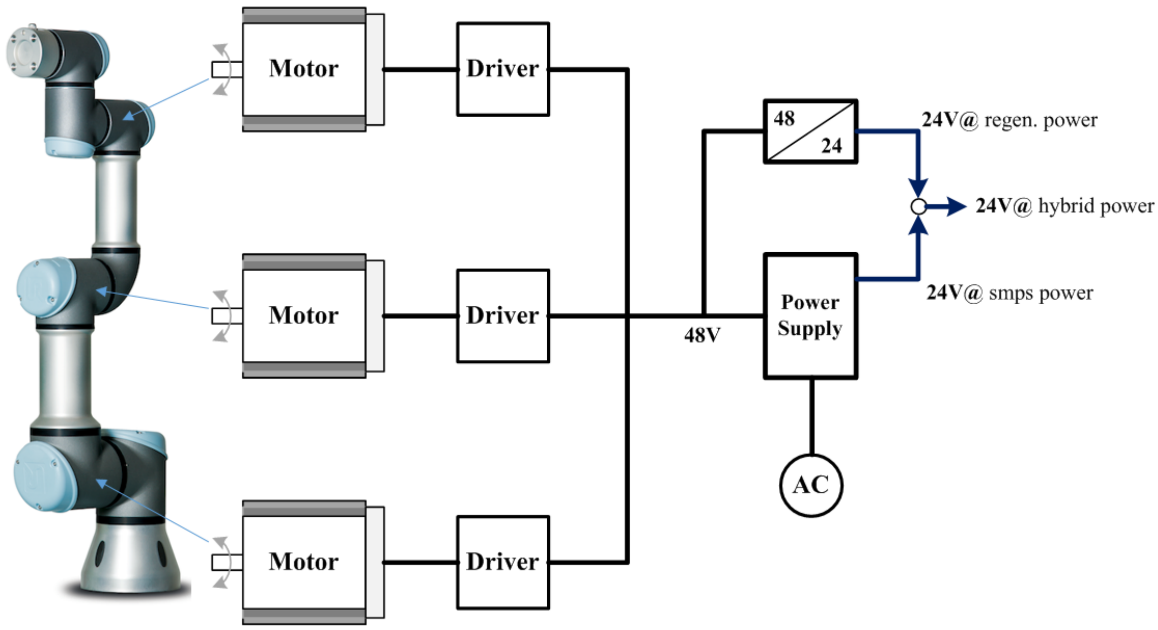

Figure 2. Proposed concept for energy efficiency improvement in 48V multi-axis robot system

Fig. 3 (left side) shows the proposed regenerative energy processing scheme and regeneration condition. In Fig. 3, the 48V to 24V forward choke converter is used to transfer the regeneration energy from the motor deceleration period into the external 24V dc power.

The resultant 24V power is the sum of the 220V to 24V SMPS power and the output of Forward choke converter(FCC). So if there is no regeneration energy, then the resultant 24V output is powered by SMPS power.

But if regeneration occurs in proportion to mechanical kinetic energy factor including operating speed, torque, the moment of inertia and a various setting values etc., then the output of FCC is contributed to the resultant 24V power.

Therefore, the proposed regenerative energy processing scheme can improve the energy usage efficiency in the 48V multi-axis robot system with a frequent accelerating and decelerating operation patterns.

In the case of a large rotating mass or the inertia effect such as a rapid deceleration due to the speed change, the regeneration energy is the following equation [6].

$$E_M = \frac{1.356}{2}(J_M + J_L)\omega_M^2 - 3 I_M^2 (\frac{R_M}{2}) t_d - \frac{1.356}{2} T_F \omega_M t_d \quad (1)$$

where

J_M =rotor inertia (lb-ft-sec^2)

J_L =load inertia (lb-ft-sec^2)

w_m = motor speed before deceleration (rad/sec)

Im = motor current during deceleration (A_{RMS}/phase)

R_M = motor resistance (ohm, L-L)

t_d = time to deceleration (sec)

T_F=friction torque (lb-ft)

From eq. 1 we can see that the energy is proportional to the square of the rotational speed. This means that if we cut the speed in half we will have only 1/4 the kinetic energy. For this reason, a uniform linear ramp to stop from a given speed results in a linear reduction in the transfer of energy from motor to drive or a linear decline in regenerative power being absorbed by FCC over the given deceleration time.

Fig. 3 (right side) shows the concept of the regeneration criteria. Whenever the direction of speed reference changes under rapid deceleration condition, there is a regeneration zone.

The regeneration zone is divided into three:

Level 3 means the maximum level for regeneration voltage and the drive will protect itself with a bus overvoltage trip, thus stopping the regenerative condition for protecting capacitor in DC bus line.

Level 2 means the start level for regeneration voltage and above this voltage the extra voltage is absorbed to FCC. Under this level, there is no action of regeneration in general. Level 1 ~ level 0 means the initial level for regeneration voltage.

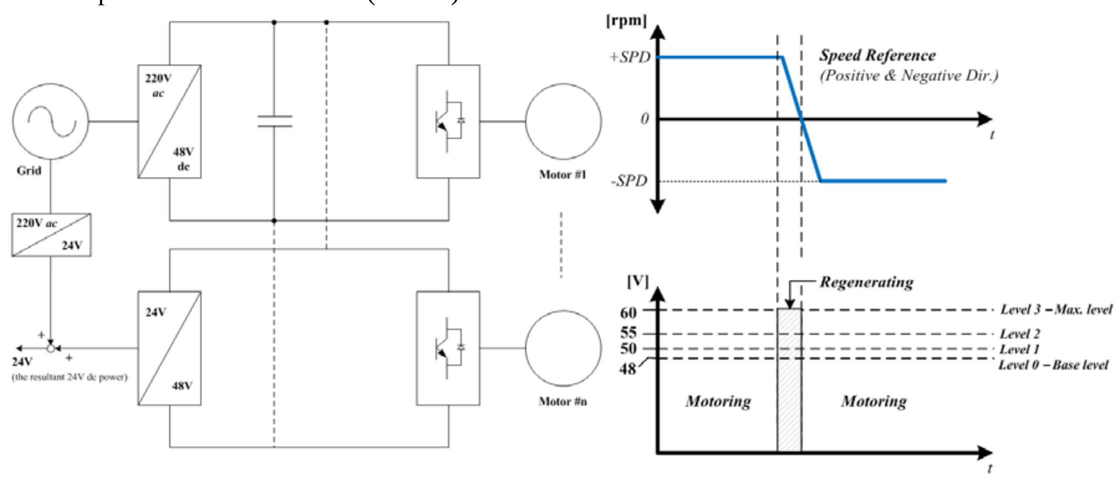

Figure 3. Proposed regenerative energy processing scheme(left) and regeneration condition(right)

As mentioned above, at the section between level 2 and level 0, there is no regeneration under the conventional operation. Because the extra voltage due to motor's deceleration is under the limit value for protecting capacitor, that is, no over-charge condition. In addition, the extra voltage is absorbed to the motor driving power at the next motoring period. However, the extra driving power due to the extra voltage is too small to contribute to the motor performance.

Although the extra voltage at the section between level 2 and level 0 rarely affect the durability of electric components for energy storage and don't help the performance of motor driving, it has regeneration power enough to supply control power for peripheral devices, cooling fan driving, small battery charging etc. in the conventional drive system.

In Fig. 3 (right side) the extra voltage between the level 2 and the level 1 at the conventional regeneration condition can be considered to the expandable regeneration section. Therefore, the regenerative section can be expanded over the conventional section by 200%. Normally, it is allowed a voltage rise up to 90% of the drive's maximum voltage rating before engaging the shunt resistor. Especially the multi-axis robot system with little more than 6 small size driver can be effective because it has no converter unit for delivering regenerative energy to grid due to high cost.

III. EXPERIMENT

Fig. 4 shows the experimental configuration for evaluating the proposed method and the mention forward choke converter (rated power 100W) for energy regeneration is developed like Fig. 5. In order to experiment, the proposed system is opend deceleration: from 0 [rpm] to 1,400 [rpm] arated under the condition of the periodic acceleration and on the contrary.

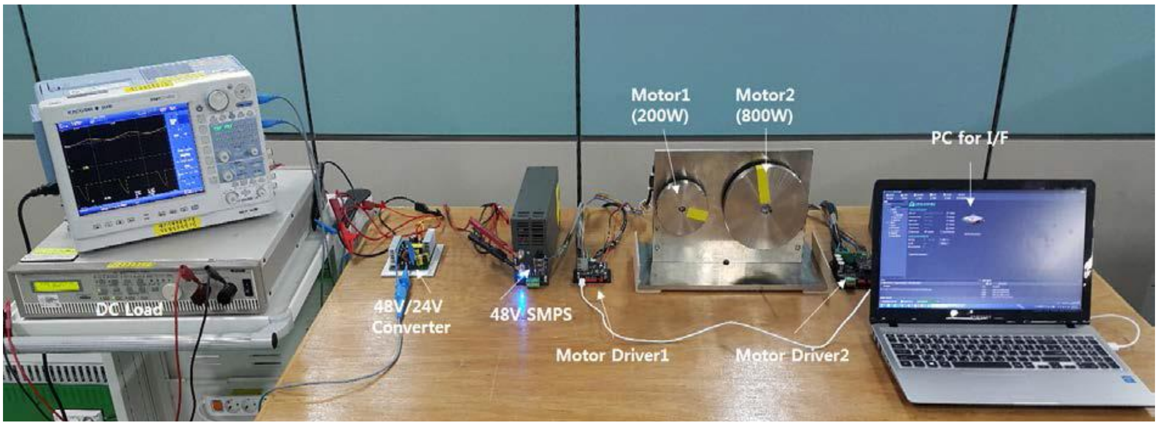

Figure 4. Experimental configuration for evaluating the proposed method

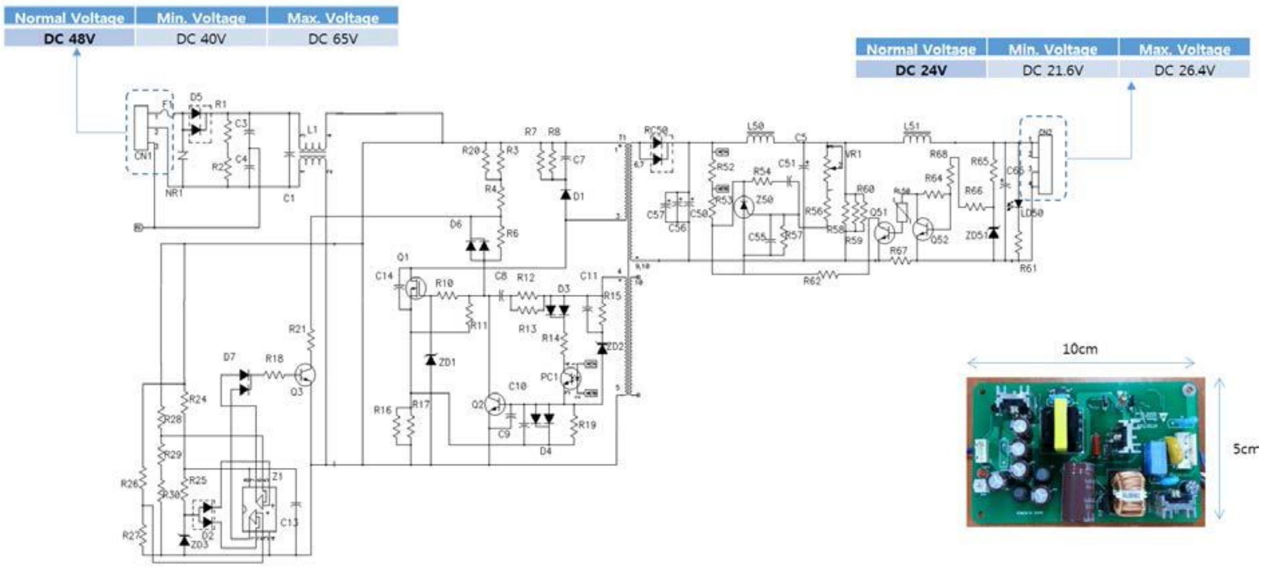

Figure 5. Block diagram of forward choke converter for the proposed energy regeneration

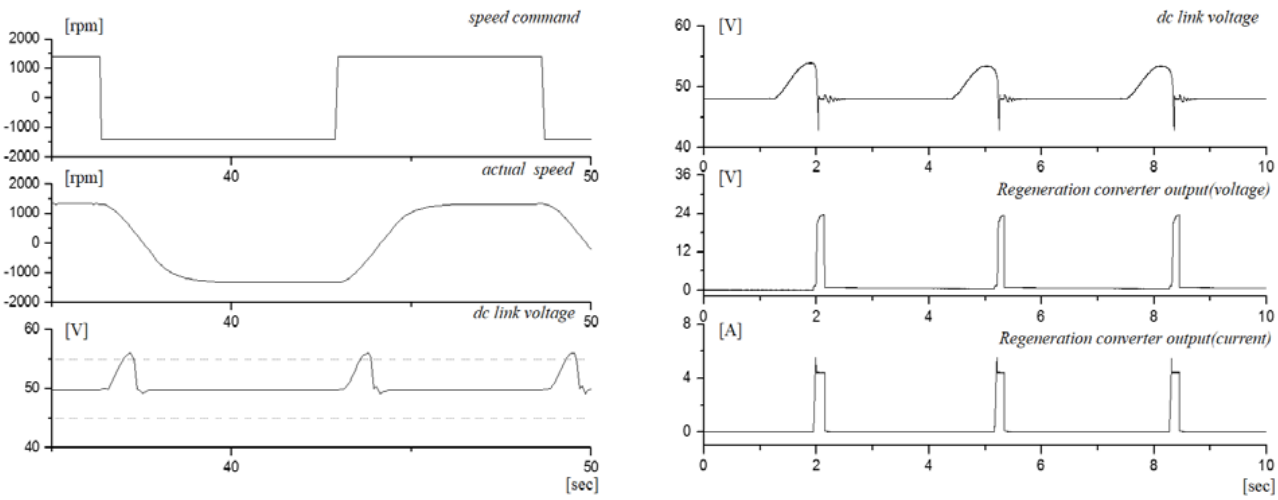

Figure 6. Regeneration converter output due to the change of speed command @1400rpm

The result of an experiment in Fig. 6 shows that through the proposed regeneration section it can supply the regeneration power about 100W (24V and 4.5A) to the external load. Therefore, the developed regeneration power can be used to the auxiliary power in the system and the effectiveness of energy usage efficiency improvement can be proved.

IV. Summary

In this paper, it is proposed the scheme of energy efficiency improvement in 48V multi-axis robot system with a frequently accelerating and decelerating operation patterns.

In addition, it is shown that the proposed regenerative energy processing scheme and regeneration condition for the multi-axis robot system is used to develop the extra power 100W (24V and 4.5A) from the expanded regeneration section over the conventional method.

The effectiveness is proved thorough the developed topology of FCC and experiment result.

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References

[1] N. Mohan, T. Undeland, and W. Robbins, *Power Electronics: Converters Applications and Design*, 2002, Wiley.
[2] B. K. Bose, *Modern Power Electronics and AC Drives*, Prentice-Hall, 2002.
[3] Variable Frequency Drives and Energy Savings, Siemens
[4] Regenerative AC Drives, Allen-Bradley
[5] Nick Papanikolaou, Theoretical and Experimental Investigation of Brake Energy Recovery in Industrial Loads, Energy and Power Engineering, 2013, pp. 459-473.
[6] [Online]. Available: Available: http://*literature*.rockwellautomation.com/idc/groups/literature/documents/at/pflex-at001_-en-p.pdf.

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