Review of Different Energy Saving Strategies Applicable To Hydraulic Hybrid Systems Used In Heavy Vehicles

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Abstract. The paper reviews the different methods to improve the performance of a hydraulic system. Facing the environment problem, the efficient hydraulic hybrid system is highly demanded. Depending on the energy storage and controlling strategy of heavy vehicles the consumption of energy, emission of exhaust takes place. This paper first analyses the recent development of energy savings of the hydraulic powered heavy vehicle. The construction machinery and the automobiles use the same hybrid power system. An efficient process is designed to store the excess energy and use the same as and when demanded by the system having frequent start-stop characteristics. In the conventional method, heavy vehicles work on the lesser amount of fuel efficiency. Some of the state-of-the-art technical skills required to improve the overall efficiency and hence the fuel economy are surveyed in this article. Also, some challenges faced by the researchers and the manufacturers in this field are discussed.

1. Introduction

Hydraulic hybrid systems (HHS) consist of a fluid power source which is pressurized, and an engine operated by internal combustion, for low consumption of fuel with a decreasing in polluted exhausts. In the HHS almost 70\% – 80\% of the vehicle’s braking / decelerating energy can be regenerated or reused. This type of system is very useful from the operational cost point of view for trucks and buses. Hydraulic hybrid systems are easy to carry because of the lightweight. Because of this, loading capacity is not affected, and that is the reason why it is beneficial for heavy vehicles.

The hydraulic hybrid system has the four most important components Reservoir, pump/motor, accumulator and the working fluid. Some of the hydraulic systems also comprise with an installed hydraulic transformer for the transformation of output flow into pressure with small power loss. In case of an electric hybrid system, the pump/motor is operated by the electric motor using the stored energy of the battery. Regenerative braking is used to charge the battery. Kinetic energy is used of pressurized working fluid for the charging of accumulators. So, we can say that the pressurized working fluid also acts as stored energy. During acceleration, pump/motor gains energy from the pressurized working fluid. Because of torque of the hybrid system, internal combustion engine experiences less amount of mechanical load which results gaining of fuel efficiency and reduction of emissions.
2. Recent Development of energy saving of hydraulic hybrid system used in heavy vehicle

There are different techniques used for different types of heavy vehicles for energy saving. For an electro-hydraulic system, the technique to reduce energy consumption is to decrease the pump pressure to its least possible value for that particular system at the time of operating the system with a proportional relief valve [1]. For frequent starts/stops of Heavy vehicles, we need a more efficient system for storage and use of high power flow due to huge energy requirement for braking. For the above type of system the merit to combine of both the batteries and hydraulic accumulator and a logical method to optimize algorithm to incorporate essential parameters in actual controlling of the torque distribution [2]. Using Potential Energy Recovery System (PERS) in an electro-hydraulic system for two different tests the maximum achieved energy-saving value is 50% for a maximum tested payload of 1000 kg and a maximum velocity of 0.5 m/s at the another test or Second Lift Zone. The free lift zone experiences 0 to 36% whether for another one it is 17 to 50%. Here the other zone is favorable due to its high value, reducing the losses of the system [3]. A variable area piston hydraulic accumulator is used to store energy through constant pressure accumulator. For all volume ratios, high energy density compared to a conventional accumulator can be experienced in this type of accumulator. When the volume ratio is 2.71:1, we get the maximum energy density which is 9.4MJ/l. The maximum volume ratio, theoretically 2:1 and practically 1.8:1, provides a greater value than the peak value of the density of energy of accumulator which is a conventional one, is 8.58MJ/l [4].

Series hydraulic/electric synergy technology is one type of energy-saving technology for the automotive vehicle. This system consists of a hydrostatic transmission drive system, an electric motor powered by a battery, hydro-pneumatic accumulator and a brake energy recovery sub-system [5]. Composite control strategy, load torque observation and control of leakage flow are the reason of improvement of the dynamic performance of the system [6]. In conventional hydraulic press idle motors consumed 40% of the input energy and 27% is available for forming. Energy consumption can increase with the increase of waiting time which is responsible for low efficiency due to the difference between the power demand and the power which is installed. Reduction of the energy consumption method is used here for a group of hydraulic presses; here the drive system is divided into some zones, because of which the difference between the storage and requirement of power in hydraulic presses eliminates. To reduce the system idle time keeping unchanged the useful parameters drive zones are divided into some group of designed hydraulic presses with a new schedule. The new schedule reduces the drive zone’s idle time and each of it needs a lower amount of installed power. Minimization of total installed power was necessary for matching the demanded power more closely [7].

Supply Power System is substituted by Load estimation based variable supply pressure valve-controlled (VPVC) hydraulic actuation method. Experimental results showed that the energy saving capacity of VPVC is up to 70% compared to the fixed supply pressure with valve-controlled actuators [8, 9]. The Electric Energy Regeneration System is more suitable for Excavator than the Regeneration System of energy which is suitable for those needed to start and stop frequently with enough spaces. Hydraulic Energy Reservation System is suitable for those vehicles needed to start and stop frequently with enough spaces [10]. Minimization of the drawbacks of the traditional hydraulic system can be done using new energy-saving hybrid system, which is called Switch mode hydraulic power supply, also pressure can be boosted up spending less power than traditional one. The pressure is increased by the sudden brake of high inertial load hydraulic system, and realization of pressure boost takes place through the discontinuous flow rate’s LC filtering and under low-pressure complementation of rate of flow takes place [11]. The most important hydraulic energy system is advanced energy-saving petroleum machinery nowadays. According to one special working theory adopt, during lowering of the pipe string the released potential energy is recoverable using one type of rig, which needs only thirty-three percent powers comparing to the ordinary rig. [12].

For urban traffic we can use the hydrostatic drive system shows good dynamic performance and good fuel efficiency. The initial system design, followed by optimum adjustment of the system controller, is responsible for 15% fuel savings [13]. The series hydraulic hybrid system is also one type of energy efficient vehicle. All efficiency of the actuator can be maximized by a set of quadratic terms is a result
of the control’s efficiency objective motivated by an actuator’s analysis within the power train. This provided a convex quadratic objective function which is solvable using Newton’s method.

Table 1. Different Renewable Energy and Energy Storage Devices

| Renewable / Alternative energy | Types of energy storage                                      |
|-------------------------------|--------------------------------------------------------------|
| 1. Biomass                    | Battery                                                     |
| 2. Geothermal                 | Compressed Air                                              |
| 3. Hydro/micro hydro          | Flywheel                                                    |
| 4. Ocean tidal / wave         | Hydrogen                                                    |
| 5. Solar photovoltaic/thermal | Pumped hydro                                                |
| 6. Wind                       | the superconducting magnetic energy source                  |
| 7. Fuel cell                  | Super capacitor                                             |
| 8. Micro Turbine              | thermal                                                     |

3. Research on energy regeneration system

A high concentration of power Electro-hydraulic systems is preferable than any other due to good strength and active response. The actuation system which uses fluid power is less energy efficient. Only 3% of the energy used by mankind is transmitted into regenerated energy [8]. The ratio of energy savings and energy utilized are determined through experimental investigation in [22]. Innovative technology is the only option for better fuel economy and reduction of the awful emissions. That’s why the concept of hybrid technology came out (i.e. series, parallel) [3]. The concept of the hybrid system of the construction machinery came from the automobile hybrid power system [23]. The pump–motors interconnected through control valves and accumulators in common pressure rail system are pertinent to the basic layout of hybridization. This type of system is having comparatively higher degrees of freedom than its conventional counterpart so far as the design parameters are concerned. The output is a constant torque when the system runs at low speed and it is power during the high-speed. The design of the hydraulic transformer is based on the speed of the transformer which is related to the speed of the vehicle. Energy regeneration takes place in the braking mode and at that time the speed of the transformer and torque of the motor fluctuate intrinsically which affects the service life and component reliability [22]. There are two energy regeneration systems according to the working cycle and structure of the hybrid excavator. The efficiency of the motor–generator system to recover energy is 17%, using this 41% of the potential energy required during lowering of the boom can be regenerated. A system consisting of motor and generator would become more efficient when accumulators are added to it for energy regeneration [24]. To improve the control operation and capacity of savings or regeneration of energy one new type of driven scheme had been used here which is a combination of pressure compensator and the device which can recover energy [25]. The hydraulic system can improve its efficiency of energy with one new type of system called the Digital Hydraulic Power Management System. There are several outlets though this is based on the digital pump/motor technology; so, depending on this, the function of the transformer can be established. For recovering of the potential energy and minimization of the hydraulic losses, the DHPMS is directly connected to the hydraulic chamber without using throttle valve. With this method also the control of displacement is necessary [26]. The effectiveness of energy of the off-road vehicle systems also can be improved using the technology-based on hydraulic losses, strategy to control and obviously hybrid architectures. But there is another way to improve the overall efficiency which has been discussed here is the minimization of the difference between hydraulic system and thermal engine. It means that researchers have tried to make machinery in which internal combustion engine is used to power hydraulic system [27].

Another type of energy saving system is the Switch mode hydraulic control system. It is installed between the hydraulic pump and the actuators. Basically, this type of system finds its application in multiple actuators hydraulic system. The Switch Mode Hydraulic Control System can be classified into two types– pressure boosts and pressure buck. The two types have been analysed through simulation and experiment [11]. In between the actuation methods, the Electro-hydraulic Servo System (EHSS)
experiences the comparable low efficiency. One supply pressure which is variable in nature and controlling of the position tracking pressure is a way to improve the efficiency of the system. A controllable supply pressure enabled EHSS can be used for the improved efficiency which can be derived using basic physics law. The pressure of supply and position of the cylinder can be controlled by a switch enabled control structure, with less energy consumption [28]. To replace proportional valves made with expensive material simple and cheap on/off valves had been used by digital hydraulics. Moreover, the effectiveness of the energy can be raised with fast switching hydraulic converters. Because of inductance recognition by a simple pipe, the energy and cost-effective inheritance systems are in the hydraulic buck converter (HBC). In this type of system, the cylinder head is connected with HBC without any other device, which results in efficient oil transport between the axis and the hydraulic power supply unit. Moreover for pressure reduction and decouple piston accumulators are used [29]. The effectiveness of the fuel can be used efficiently in a hybrid hydraulic excavator using the Energy regeneration Systems with the energy storage device used by the hybrid power system. The traditional orifice control system is more efficient than the conventional Energy Regeneration Systems. The problem of overloading and the capability should be minimized of both the hydraulic motor and hydraulic generator. An Energy Regeneration System which is compound in nature can act as a combination of the accumulator of both types electric and hydraulic. This system is able to regenerate 39% of the total potential energy instead of 36% like a conventional one and also improved efficiency is achievable under standard operating conditions. From the results, it is also noticeable that the new system can control in a better way than the conventional one with less than 35% capacity of the regenerator [30].

Technology now days are accustomed to variable speed though most of the motors are made to maintain the constant speed. For controlling the speed, rotational force and output torque of mechanical equipment one new type of drive is used are called Variable Speed Drive (VSD). The energy savings and productivity management of mechanical equipment can be done in an efficient way using VSD [31]. For existing hydraulic hybrid excavators, the loss of energy is still too large and the energy recovery efficiency is not high enough. To eradicate the problem one new type of system is introduced by the researchers which consist of three chamber cylinders (TCCs) with accumulators. There are some of the chambers with the piston rod and without a piston rod and also counterweight chamber. The accumulator is connected with the chamber with counter weight. A pump controlled system consists of a variable pump, the inlet of the pump is connected with the chamber with the piston rod and the outlet is connected with the chamber without piston rod. Simulation of the dynamic response and each component characteristics were analyzed by mathematical model also the parameter matching accumulator had shown. Each cylinder dissipation was obtained from the simulation and compared with the without potential energy recovery dissipation. Using this system 30~60% of the reduction in energy dissipation of the variable pump and 50% for the engine had been recorded [32].

Accumulators in hydraulic system act as a storage of energy and minimize the pressure variation of the system. These two are the major drawbacks of the conventional system. An accumulator that uses a piston with variable stroke area used to maintain the pressure of the system during changing of the gas pressure. Fabric reinforced rolling diaphragm is used to seal this type of piston. The piston radius acts as the function of the piston displacement and it converts into a function of axial contact location between the piston and the diaphragm. Numerical solution of this profile of the piston under different loading conditions by both the transformation methods is to increase the exchange of geometric design. The gas volume ratio is 1.8:1, which was maximum during the use of a piston with a variable area under a fixed cylinder area. Using this type of accumulator the density of energy recorded to be improving by 16% than the conventional one where the volume ratio is 2.71:1, and also the energy density is higher when the ratio is 1.8:1. A constant hydraulic system pressure which is independent of stored energy, easy controlling of the system, elimination of the other circuit components to get equal power requirements, and moreover high energy density—these are some advantageous feature of this system than conventional one [4].
One effective way for reduction of the energy consumption is potential energy recovery (ER); though, the system for energy recovery with a strategy of directly speed control is to increase the oscillation of the actuators because of reduced damping comparing to the conventional one. In this paper, researchers had concentrated into the improvement of the performance of the boom with proper design of the energy recovery controller. Mathematical modeling of hydraulic as well as electrical component had done considering the system dynamics. To achieve the efficient performance within the total velocity range one composite control strategy which is staged had been proposed. The permanent magnet generator speed stiffness and the boom motion stiffness could be increased by Load torque observation. The anti-disturbance capability and control system accuracy is affected by the leakage flow [6]. The energy loss due to throttling is one of the major problems for hydraulic cylinder drive. A Switched Differential Pump with variable speed can be used to drive the hydraulic cylinder directly. To operate a differential cylinder, three fixed displacement gear pumps which are oppositely oriented connected with the rotary drive through the shaft. To guarantee a high value of stiffness of the drive, the construction had been done in such a way that the pressure at transmission line increase for pump outflows which is much more than the pump leakage, and to achieve the desired pressure level the flow has to be bleed off from the transmission line through proportional valves [33].

The hydraulic energy recovering work over rig is three times more efficient than the advanced petroleum machinery energy saving rig, and also it is able to recover and reuse the potential energy, which is released by the pipe string during lowered rig. According to an analysis, it had shown that at the time of lowering the pipe string of weights 260 kN, 240_106 J of energy is recoverable [12]. There are different ways to store the energy recovered from the system. Accumulator storage is one of them, though it has a problem of energy losses. But heat recovery plays an important role in the improvement of system efficiency [34].

4. Electric energy storage of hybrid system
The conceptual design of energy storage system (ESS) depends on the flow of electricity through a common BUS. Different ESS are designed as per the suitability of BUS design in such a way that the normal flow of energy should not interrupt. There are three types of classification of ESS according to Nehrier et al. [23], which are: DC-Coupled systems, AC-Coupled systems and hybrid systems. All of these are made as per the sources of energy available and loads. Hybrid systems and construction machinery are generally consisted with DC Bus because of its complex structure and usable within a limited space. The below fig.1 is a DC Bus system. Motor or generator also plays a major role in deciding the structure of an ESS for particular hybrid vehicle or construction machinery. If the voltage of a DC motor or generator is different from the ESS, then DC converter is used to match the voltage of the two devices, for a hybrid system. But in case of an AC generator or motor, AC–DC converter is needed to match the voltage of the ESS with the generator or motor. The ESS structures are as follows.

4.1. Hybrid energy storage system
In earlier days hybrid vehicles used this type of system. The requirement of the density of high power was met by this system. Because of energy density with very high value, small size, light weight also it had a very wide use [35-41] ESS structure consisted of batteries, super capacitors and fuel cells are discussed in the study [42-45]. Battery and super capacitor can use full of its merits when it is connected with a hybrid system. That’s why it has a wide use in the HHS. There are seven types of hybrid ESS structures described by Ostadi et al. [46]. One or two DC–DC converters and a DC–AC converter are taken in between the connection of the battery, super capacitor, motor with AC electric current and DC Bus. Connection structure which is direct and connection structure which is indirect is the simple classifications of the all that seven type of system [47]. No capacitors are used in between the connection of the DC bus and super capacitor, battery in case of a structure which is direct. The Fig 1. (a) Shows above type of structure. In this type of connection voltage of the bus matches with the capacitor and battery. The internal resistance decides the ratio of distribution of energy in an uncontrollable manner. Based on this, absorption of energy or release of energy takes place [48, 49]. The opposite of the direct
connection structure is called indirect connection structure, which consists of a converter in between DC bus and a super capacitor or battery connection.

4.1.1. A subsubsection Connection of a structure consisting super capacitor to DC bus with DC–DC converter. A structure with indirect type connection is shown in Fig. 1(b). When there is no power converter in between the super capacitor and DC bus it starts to fluctuate. It happens during charging or discharging. Here the super capacitor is used to supply power during fluctuation and the battery fulfills average power requirement. The system efficiency reduced during the charging and discharging of the super capacitor because of very frequent operation of the converter.

4.1.2. Connection of a structure consisting battery to DC bus with DC–DC converter. Another type of indirect connection is shown in the structure of Fig. 1(c). In this case required power is supplied by the battery and required power during fluctuation is supplied by the super capacitor. That’s why the frequent switching by the converter reduced and because of that, there is a chance of improvement of the efficiency of the system. Isolation of input/output can be realized by the converter since the terminals are not connected. The long battery life can be observed because of doing isolation of the battery and the DC bus using the converter, leading to the minimization of the fluctuation of the current. But if there is a direct connection between the super capacitor and the DC bus, the voltage of the super capacitor gets a chance to change sharply, leading to a harmful impact on the efficiency of the system motor. This type of system consumes fuel more than the indirect connection with low system efficiency.

4.1.3. Connection between the DC bus and battery, super capacitor with a DC–DC converter. There is one structure of the indirect type which overcomes the drawbacks of Fig 1(a), (b), (c). The reason behind the success is that here both the battery and super capacitor are connected with converter separately and also separated from the DC bus. Therefore, depending on the state of charge the absorption and supply take place. The additional converter can increase the efficiency of the system; transformation is responsible for the decrement of the efficiency.

Fig. 1. Schematic diagrams of different types hybrid energy storage system
4.2. Battery enabled energy storage system

The vehicles and construction machinery consists of a hybrid system, generally uses battery and motor in their particular energy storage system. That’s why it has a wide application in manufacturing of the construction machinery and vehicles consist of the hybrid system. There are many multinational companies and research institutes for construction machinery and vehicles use the above-mentioned structure. Kobelco is one of the most renowned companies in this respect. Fig.2 shows the conversion of a hydraulic excavator from traditional one–Kobelco 70SR. The motor and the swing system of the engine are assisted by the battery with energy supply. But during braking and acceleration, due to the fluctuation of the energy, the battery requires more power than the average to supply to the system and that is supplied from the electric swing motor or power generator. A Hybrid excavator is 40% more efficient in terms of consumption of fuel and reduction of emission than traditional one. Another type of hybrid excavator or construction machinery which consists of a set of a 288 V Ni–MH battery, a 10 kW engine assists motor, power generator and a 10 kW swing electric motor. For long life of the energy storage system, it should work within an area which consists is of high efficiency. To get the desired goal the state of charge is set to a certain range which can fix it. Depending on this the maximum range of charging and discharging is set to control the energy storage system. It makes the system more fuel efficient and harmful emissions due to digging and loading reduces to a certain level. Fig.3 shows one type of excavator which consists of a hybrid structure, parallel in nature and pump drives all the actuator [52]. Determination of the motor and generator’s mode as per the power of the pump can be done by the release of power by the controller of the system. Depending on the range of state of charge and fluctuation of the load power energy storage system the mode of work allocation of torque are decided.

![Schematic design of hybrid excavator of Kobelco](image-url)
4.3. A Super capacitor enabled energy storage system subsection

The hybrid excavators of a medium size generally use this type of structure. The major energy storage element in this type of system is a super capacitor. In case of the hybrid system, there is a separate use of motor and generator during the recovery of energy. Electric swing system plays a major role in the reduction of power of the engine and the cost of the entire system. This type of system is 21% to 41% efficient in terms of savings of energy. There is one another type of excavator which uses a parallel hybrid system made by Hitachi, uses an electric swing system, travelling system and system for regeneration of energy. There are two types of controller known as master and slave, which operates the system of control. The job done by the master controller is supervision and electric swing system is responsible to take that one. The slave controller is responsible for controlling the electric travelling system. Depending on the signal of operation and feedback, the control on the engine, hydraulic pump, control valves, generator, and rectifier/inverter is done by the master controller. The charging and discharging of the super capacitor is controlled by the state of charge. This is done under the supervision of the master controller through the salve controller. The efficiency of the system depends on the mismatch of the two controllers. The mismatch as much as low the overall efficiency is high as much as it can. Also, there are lots of contributions in the reduction of fuel consumption by the regeneration system for energy and electric swing system. This type of system is 25% energy efficient. According to Kwon et al. [53], the hybrid structure which is compound in nature can be more efficient than the others. The above decision came after making a survey of the various types of excavators in respect of comparison of some factors like consumption of fuel, a cost which is additional, payback time etc. Here all types of excavators is used i.e. series, parallel, compound. Algorithm for control which is made on the basis of the equivalent fuel minimization strategy with a regulator of the speed set by the engine is proposed by Kim et al. [54]. The above proposal had been done considering the hybrid excavator compound in nature, after replacement of the hydraulic swing which is conventional with a swing motor which is electrically propelled. This type of excavator system structure is 30% more efficient than the conventional one in respect of fuel consumption.

4.4. Hybrid energy storage system consists of super capacitor and battery

This type of engine is able to carry heavy loads as well as light loads. During the light load carriages, the energy storage system absorbs the excess energy and this will be supplied at the time of heavy load.

Fig. 3 Hybrid excavator of the company new Caterpillar and Mitsubishi
carriages. This is more fuel-efficient than the conventional excavator. In this type of system energy storage system consists a set of Ni–MH batteries which have a capacity of 6.5 Ah, rated voltage of 288 V, 11.4 F and 304 V rated super capacitor. The engine efficiency is high and this is achievable using the current distribution between the DC bus and battery, super capacitor. The DC bus voltage algorithm is responsible to control the De bus voltage or to keep it constant, and the load power controls output power [55]. This is one of the very high fuel-efficient machines, able to save up to 60% of its energy comparing to the conventional one.

As per the above discussion batteries, are one of the essential parts of the hybrid systems. Super capacitor is also used instead of a battery. The difference between the super capacitor and battery is that the higher efficiency and long life cycle can be achievable by using super capacitor while the battery is known for its high energy density. Usually lead-acid batteries are used in HHS. Example – Ni–MH battery and lithium battery. There is a comparison between the common energy storage elements shown in Table 2.

Table 2. Comparison between commonly used energy storage elements

| Type         | Energy density (Wh/kg) | power density (W/kg) | Cycle life (Times) | Efficiency of charging & Discharging (%) | Merits                                      | Demerits                                      |
|--------------|------------------------|----------------------|-------------------|------------------------------------------|---------------------------------------------|-----------------------------------------------|
| Lead-acid    | 30–40                  | 200–300              | 300–400           | 75                                       | Low cost, high discharging rate and high recycling rate | poor performance at low temperature          |
| Ni–MH battery| 60–80 800–             | 800–1500             | >1000             | 75                                       | High energy density, high charging and discharging rate | High self-discharging rate need for cooling system and higher manufacturing cost |
| Lithium Battery | 100–200             | 600–2000             | >1000             | 90                                       | High voltage, high energy density, light weight. | Life reduces at high temperature, non-overcharge and high-security requirement |
| SC           | 4–15 1000–            | 1000–10,000         | >100,000          | 85-98                                   | Fast charging and discharging speed, Pollution free and long life | Low energy density                           |
5. Advantages of New System of Regeneration of Energy and Strategy of Controlling for Hybrid Hydraulic Excavators

The advantages of the above-mentioned processes are listed below:

i) During lowering of the boom we can get electric energy and hydraulic energy both from the GPE, depending on hydraulic accumulator pressure it decides.

ii) As the energy can be stored in the hydraulic accumulator in very short time, a sub-capacitor can be a battery. Limitations of generator’s points of working within an efficient region affect the recovery efficiency.

iii) The hydraulic accumulator uses to downsize the generator power and the hydraulic motor/pump [30].

6. Future Direction

With increasingly severe emission and energy shortage, it is a great demand in the present scenario to design more fuel efficient and less pollutant machine. It is necessary to improve the design of regenerative energy system to reduce the fuel consumption without sacrifice the control performance compared to the conventional hydraulic energy. A new regeneration unit including integration of the hydraulic motor and generator, integration of the cylinder and the hydraulic accumulator can be a key factor to the Energy Regeneration System in future. Except for the potential energy and the kinetic energy, the pressure drop energy in the hydraulic system is recoverable which can reduce the fuel consumption and energy loss in an efficient and much better way than the conventional system which leads to the improved performance of the hydraulic system.

7. Concluding Remarks

Most of the commonly used energy-saving strategies in case of heavy vehicles, especially those used as construction machinery are surveyed in this paper. It provides a brief historical overview of the technology and discussed some issues which are imperative for its success. In addition to this, the concept of energy regeneration without compromising the system performance is also reported. It plays a major role in the manufacturing of this type of construction machinery as well as operating cost of the system because of the reduced fuel consumption.

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