THE ROLE OF THE ePUMP

The role of the ePump when transitioning from an ICE to an Electric System in Mobile Equipment.

Parker

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Introduction

Regardless of the type of work being done, your equipment requires reliable technology to supply the necessary level of power for as long as it is needed. Due to growing environmental concerns, many mobile equipment manufacturers are moving from diesel engine-driven hydraulics to electro-hydraulic systems.

As the world transitions from internal combustion engines (ICE) to electrified systems, the mechanism for driving traditional hydraulic technologies transitions with it. No longer is a power take-off (PTO) required for transmitting rotational energy from the ICE to the hydraulic unit. In the age of electrified systems, a hydraulic unit can be mounted, either directly or through a coupling, to a variable-speed electric motor controlled using an inverter for mobile applications.

A coupled motor and hydraulic pump (ePump) are composed of various hydraulic technologies, each having benefits and drawbacks. There is no one-size-fits-all solution for the virtually infinite number of mobile applications. This paper will help engineers better understand what to consider when designing an electrified system for mobile applications and demonstrate energy savings for specific mobile applications through a case study.

Left to Right: GVM + IGP, GVM + Bent Axis, GVM + P1M

Choosing the Right Hydraulic ePump for Your System

Historical precedence has taught us that there is an optimal hydraulic technology for a given application based on desired characteristics or specifications. A combination of multiple factors, including speed, pressure, cost, and many others, would lead to a decision on which hydraulic technology was best for a given system. With an electrified system, the overall process has not changed. However, some of the hydraulic pump characteristics carry more weight than they previously did.

The speed of the hydraulic pump is no longer limited by the operating speed of the PTO but instead is limited by the design characteristics of the pump itself. Previously, the size the pump was determined by the required flow at a predetermined speed (1,200 1,800 2,100 RPM etc.) which typically fell below the maximum operating speed of the hydraulic pump. This resulted in a larger pump being selected. The larger pump had minimal impact due to the inexpensive cost of diesel as a fuel source. Now, reducing the pump size is critical in optimizing battery requirements for a desired system and duty cycle.

The cost of a hydraulic pump used to be one of the main deciding factors when specifying a system. In an electrified system, however, the cost of the hydraulic unit is generally a small portion of the entire system, considering the cost of the motor, inverter, batteries, and cabling. There are other trade-offs when focusing on hydraulic costs that may not have been considered in a traditional ICE system, including, but not limited to, noise and efficiency.

Noise generated by a hydraulic pump was once an afterthought in many applications since the sound generated by the ICE would eclipse that of most hydraulic pumps. The removal of the ICE from the system can, in many instances, make the noise of the hydraulic pump become more pronounced. Noise generated from a hydraulic pump is split into three categories: mechanical, fluid, and system born noise. All three types of noise will need to be considered when selecting the best hydraulic pump and architecture for your system.

The efficiency of the hydraulic pump also used to be an afterthought when determining which type of hydraulic technology to use for a given application. This is likely to change in an electrohydraulic system where even a few percent of variation in efficiency can have a large effect on the total cost of the system or desired run time. Efficiency needs to be considered not only when sizing the battery but also for the ancillary effects of inefficiency in the hydraulics, such as heat generation and dissipation.

The above are a few of many attributes that need consideration when properly selecting the optimal hydraulic unit for a desired system. The main thing to keep in mind is that each characteristic has tradeoffs. A higher efficiency pump may cost more, lower noise pump may not be as robust, or incorporating a variable displacement pump will likely increase system complexity.

Choosing the Right Hydraulic System Architecture

When considering making the transition from an ICE to an electrohydraulic system, choosing the correct hydraulic unit is a small piece of a much larger puzzle. Electrohydraulic systems are composed, at a minimum, of a pump, motor, inverter, and sometimes valving. There are considerations to be taken at each component level to engineer the optimal system for the desired application.

Centralized hydraulics is where most OEMs decide to start their electrification journey. In this type of system architecture, the ICE is removed and replaced with a large electric motor coupled to an existing PTO with all the previously specified hydraulic pumps and valving in place. While this is a good first step, it generally results in a costly, inefficient, oversized system. The system, keeping its old architecture requires the electric motor to always be rotating at a constant speed with the hydraulics doing the same. Fluid, especially in fixed displacement systems is always flowing and needs to be diverted back to the tank when not in use through valving. This means that even at ideal, the system is using energy and draining the battery. This is compounded with the fact that a motor spinning at lower speeds, to mimic the ICE, is operating well below its optimal efficiency resulting in additional losses, heat generation, and increased power consumption from the battery.

Decentralized hydraulics deconstructs the traditional hydraulic architecture to allow for point of use hydraulic power. Unlike the previously discussed, a decentralized hydraulic system allows for smaller ePumps to be used for a specific function. There are two major benefits of decentralized hydraulic systems. First, due to each ePump having a specific function both the motor and pump can be sized appropriately, saving component costs, decreasing installation envelope, and increasing both component and system efficiency. The second and most important benefit of a decentralized hydraulic system is the ePump can be shut off when not in use. Deenergizing the ePump when not in use will increase product life while also greatly reducing battery utilization. No longer is the battery power being consumed while the system sits at idle.

CURRENT STATE
ICE, centralized architecture

FUTURE STATE
Electric powered,
centralized architecture

OPTIMAL STATE
Electric powered,
decentralized architecture

Sizing your ePump

Sizing an ePump is similar to sizing a traditional pump for any hydraulic application. First, the pressure and flow requirements for the application must be determined. Next, the size and type of hydraulic technology will need to be determined: size based on displacement and operating speed, and hydraulic technology based on previously described attributes. Once the pressure, flow, and displacement are determined, the required torque at a given speed will need to be calculated to size the motor appropriately. Finally, to properly size the inverter, understanding of the voltage and current is required. The voltage is predetermined by the characteristics of the battery selected and the current is determined based on the motor properties at given speed and torque values. This information should be provided by the motor and battery manufactures.

PUMP
Flow and pressure requirements

MOTOR
Motor size

INVERTER
System voltage

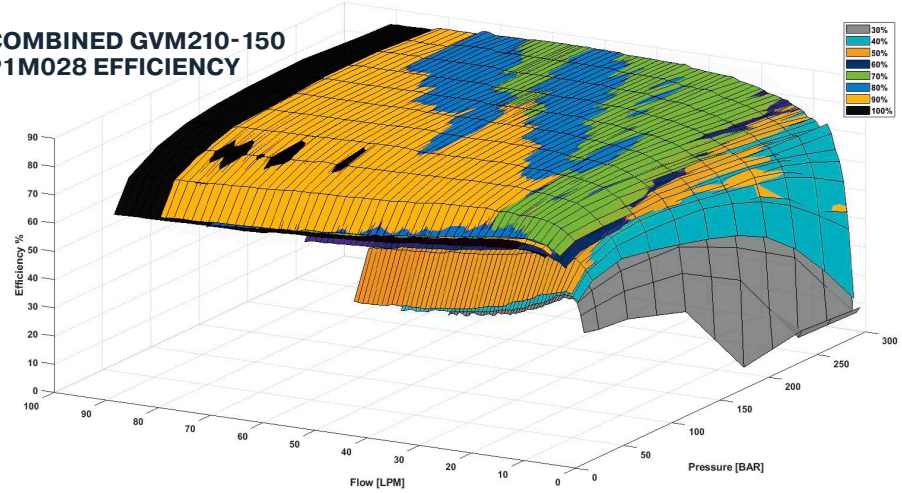
Fixed vs Variable Displacement ePumps

In the world of hydraulic pumps there are two main categories that all hydraulic technologies fall under: fixed, and variable displacement. A fixed displacement pump is one in which the amount of fluid pushed per revolution is constant and based on the design of the pump. A variable displacement pump is the inverse of its fixed displacement counterpart. In a variable displacement pump the amount of fluid pushed per revolution can vary between zero and the maximum designed displacement of the pump.

Traditionally, a variable displacement pump would be used in a system where the user or application wants to vary hydraulic power by varying the amount of flow with a constant speed. This would lead most to ask the question if variable displacement ePumps would be necessary when using a fixed displacement ePump system, could the hydraulic power be varied through changes in speed? The answer is a resounding yes. Variable displacement ePumps have numerous advantages over their fixed counterparts, including the ability to optimize efficiency, reduce heat generation, and downsize components.

As previously discussed, an electrohydraulic system is composed of three different technologies: the pump, motor, and inverter, each with its own optimal efficiency operating parameters. Therefore, determining the optimal efficiency for the electrohydraulic system for given hydraulic power becomes a balancing act. In most cases, the end user desires a specific pressure and flow to do some arbitrary work function, and they do not care how it is achieved. With a fixed displacement ePump, the only variable that can be changed is the rotational speed to achieve the desired flow. In a variable displacement ePump, both the speed, and displacement can be varied to achieve the flow required to perform the desired work function, giving the system the ability to operate in the most efficient zone possible for all three components. A combination of experimental and simulated data indicates that a variable displacement piston ePump is up to 15% more efficient when operating at variable speed and displacement in peak efficiency zones compared to an identical model in which the pump is locked at full displacement and only the speed is varied.

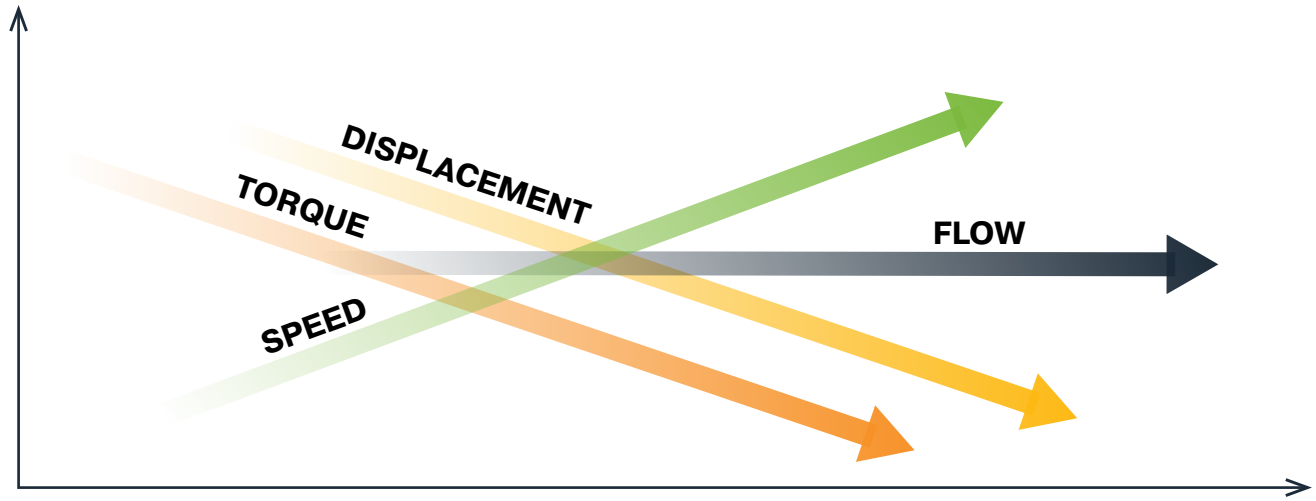
COMBINED GVM210-150 P1M028 EFFICIENCY



Another key advantage of a variable displacement ePump is the ability to reduce motor heat generation during operation. It is reasonable to think that since electrical power into the motor is equal to hydraulic power out of the pump minus inefficiencies, motor heat generation could be controlled by varying speed, reducing flow, and lessening power consumption. While it is true that a reduction in speed would reduce power consumption, it is not the case for heat generation. Due to the natural operating principles of a permanent magnet AC motor (PMAC), voltage controls speed while current produces torque, and it is current that is directly related to heat generation. In some instances, reducing motor speed has the opposite effect on heat generation by causing the motor to operate in less efficient zones, further increasing temperature.

In a PMAC motor, the amount of current produced is a result of the torque constant Kt, which defines the direct torque-current relationship of a motor. Therefore, reducing the system torque reduces the motor current and subsequently reduces the heat generation inside the motor. Torque is determined by the pressure and displacement of the hydraulic pump. Since pressure is determined by the desired work being performed and, therefore, fixed, the only way to reduce the torque required by the motor is to reduce the displacement. This is only possible in a variable displacement system. As a bonus, if the hydraulic unit is not already operating at the maximum allowable speed, the motor speed can be increased in tandem with the decreasing displacement, resulting in maintained flow and no noticeable variation to the operator.

Lastly, one of the major advantages of a variable displacement ePump is the ability to downsize components dependent on the duty cycle. There are specific duty cycles, such as work holding or material handling, that really benefit from the implementation of variable displacement pumps in electrified systems. In these specific applications, there are portions of the duty cycle which require low flow but high pressure. During these points in the duty cycle, motor torque can be decreased by maintaining constant speed and decreasing the displacement of the hydraulic unit. An example of how this can help downsize components is discussed in the next section.



Fixed vs Variable Case Study

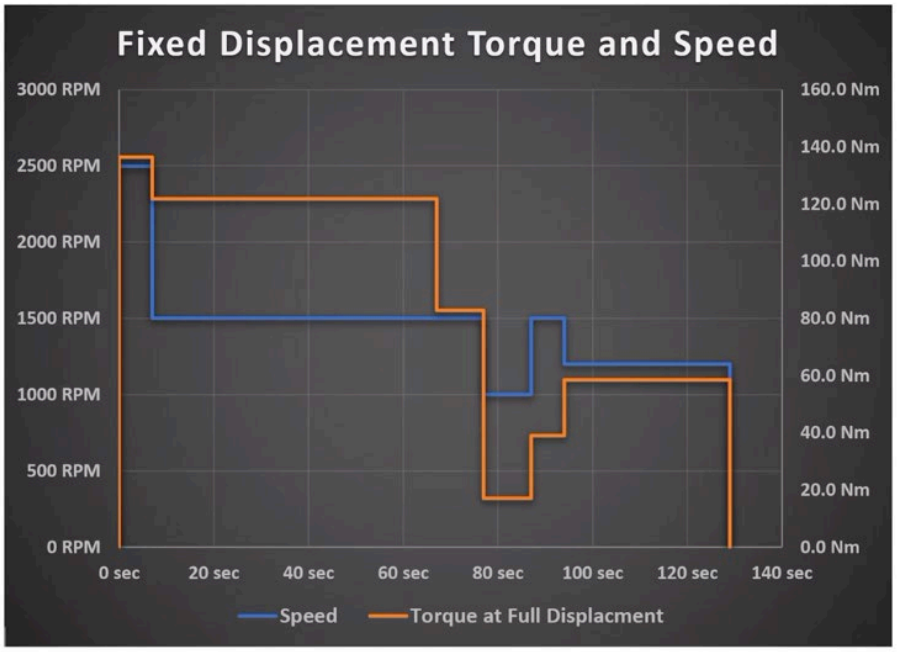
In this section a case study was completed for a hypothetical material handling duty cycle. In the duty cycle a container is lifted and moved to a new location where it is placed before the equipment repositions itself back to its original location to pick another container. The required duration, flow and pressure for each step are outlined in Table 1.

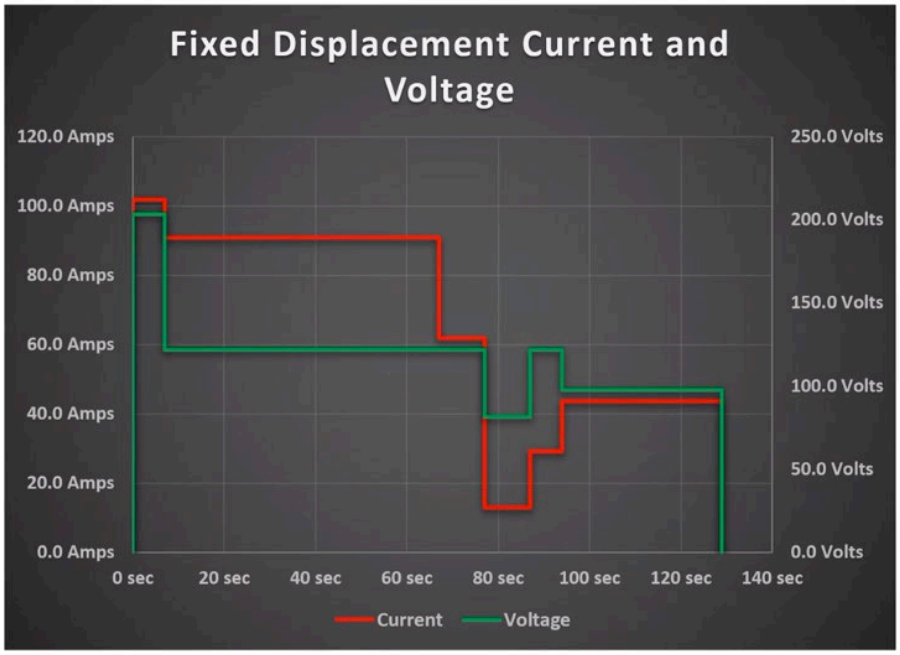
STEP	TIME	PRESSURE	FLOW
Pickup container	7 sec.	190.5 Bar	112.5 lpm
Move container to new location	60 sec.	170.1 Bar	67.5 lpm
Place container	10 sec.	115.6 Bar	67.5 lpm
Reposition equipment with lift raised	10 sec.	23.8 Bar	45 lpm
Lower lift	7 sec.	54.4 Bar	67.5 lpm

Table 1: Material Handling Duty Cycle

To achieve the required flow and pressure, a 45cc fixed displacement pump with a mechanical efficiency of 90% was selected. This means that the motor used to drive the hydraulics must be capable of achieving a continuous torque of 135Nm at 1500 RPM and a peak torque of 151NM at 2500 RPM. To achieve this, a Parker GVM210-150 motor with a PBT winding was selected with a torque constant of 1.344 Nm/Arms and a voltage constant of 81.23 Vrms/kRPM.

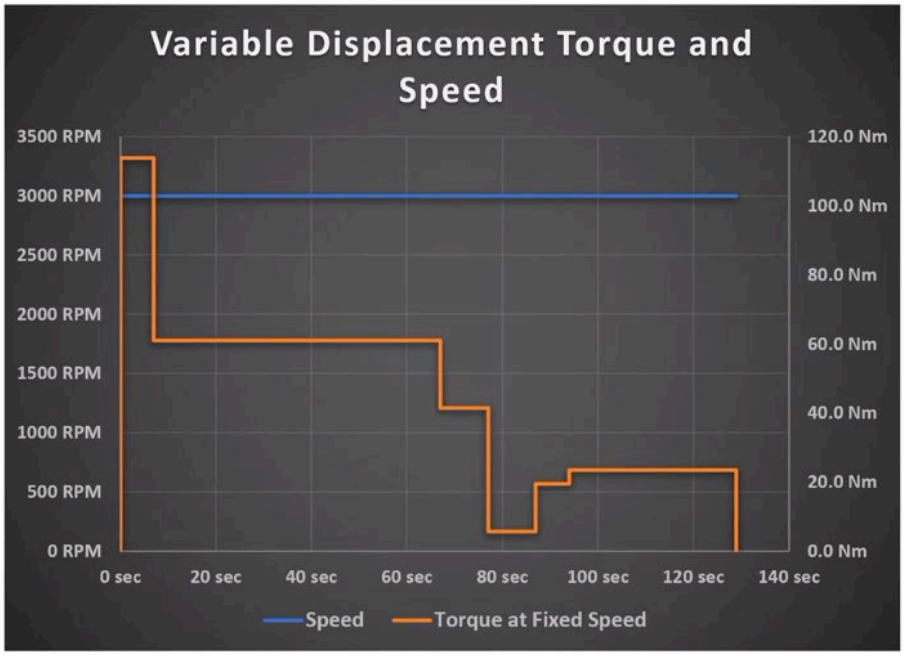
If the same duty cycle is considered but the fixed displacement pump is exchanged for a variable displacement unit, the required speed and torque would look very different. A variable displacement system can operate at speeds allowing for optimal system efficiency, which in this example would occur at 3,000 RPM, and displacement varied to meet flow requirements.

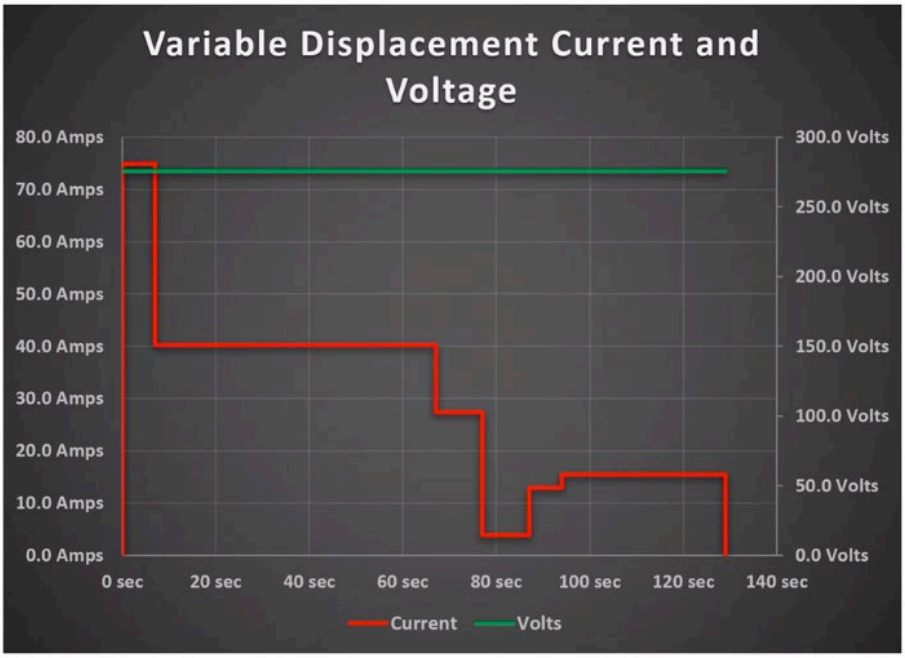




During the phase of the duty cycle, when the unit is moving an object at a fixed elevation off the ground, minimal flow is required at high pressure. The minimal flow requirements allow the displacement to be reduced, reducing the motor torque in tandem. Therefore, a required motor for this variable displacement system would need a continuous torque of 68 Nm at 3000 RPM and a peak torque of 127 Nm at 3000 RPM. These requirements would yield a Parker GVM210-100 with a PDD winding, which has a torque constant of 1.519 Nm/Arms, decreasing component size, reducing implementation cost, and decreasing power utilization for the same duty cycle.

This system with a smaller motor will result in multiple points of savings. First, the initial investment cost decreases through multiple avenues, including reduced motor cost and smaller cabling. Additionally, the increased torque constant will decrease the amount of current required for the same torque values, resulting in further savings by decreasing the amount of battery required for the same desired work. At roughly $300/kWh, the battery savings alone could be in the multiple thousands per machine. Finally, the smaller battery requirements also result in decreased energy utilization for charging the unit during downtime.





Conclusion

When transitioning from a traditional internal combustion engine to an electrified system, multiple new considerations need to be taken. Speed, cost, noise, and efficiency are just some of the attributes that need to be considered when properly selecting an optimal hydraulic system. Understanding the advantages and disadvantages of centralized and decentralized hydraulics will optimize the machine for the work required and help size the best ePump for the application. Finally, as demonstrated by the case study, evaluate the tradeoffs between fixed and variable displacement ePump systems. Understand how variable displacement systems can yield optimal thermal management and efficiency characteristics, with the ability to downsize components. The topics discussed in this paper are just a few of the considerations to think about when transitioning from an internal combustion engine to an electrified system. It is always best to reach out to a trusted engineering partner when taking the next step in the electrification journey.

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