ENERGY CONSCIOUS AC DOMESTIC BOOSTER SYSTEMS

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If you are fortunate enough (or unfortunate, depending upon one's perspective) to live off the electrical grid, efficient energy usage becomes paramount. Regardless of whether the energy source is wind, water, the sun, or some combination there is seldom an excess of stored power. If the domestic water source is a lake, well, or rainwater catchment the water pressure booster can be one of the largest loads on an inverter.

Now, you may be wondering why I did not use *Efficient* instead of *Conscious* in the title. Well, when small electric motors and pressure pumps are involved, efficiency is relative!

Electric motor efficiency is defined as the ratio of the mechanical energy produced versus the electrical energy consumed in producing it and is expressed as a percentage.

% Motor Efficiency = me / ee

If a motor could be made 100% efficient, it would consume 742 watts for each horsepower of mechanical energy it produces. Large three phase motors can be extremely efficient and larger ones approach 97%. Single phase motors, the ones that run on household current, are not nearly as efficient and, as their horsepower rating decreases efficiency drops even lower. Fractional horsepower motors like the ones found on domestic pressure pumps and hot water circulators are the least efficient of all. For example, if a typical 1/25 HP, 115 VAC solar circulating pump were 100% efficient it would consume only 30 watts. Its actual consumption is a whopping 95 watts and its efficiency is a mere 30%.

Unfortunately, that is just the beginning. Pumps convert the mechanical energy produced by an electric motor into hydraulic energy, the energy that causes water to flow, pressure to increase, or both. Pumps can also be quite efficient and large ones approach 90%. But, like fractional HP motors, small pumps are inefficient. In fact the Jet pump, the most common domestic pressure booster pump, is extremely inefficient by design. It recirculates a portion of its pumpage through a venturi which allows it to produce a much higher pressure than a conventional centrifugal pump of the same horsepower. A price must be paid for this pressure increase and it comes in the form of a hydraulic efficiency that is less than 50%.

And, it doesn't stop here either! The total efficiency of the machine (pump & motor), something we call *wire to water* efficiency, is the product of the two individual efficiencies. A typical 1/2 HP jet pump with a motor efficiency of 55% and a pump efficiency of 50% is less than 28% efficient overall. In other words, for every kilowatt of power consumed only 275 watts is used to deliver pressurized water.

The purpose of this rather lengthy introduction is to illustrate the point that we have little or no control over the energy efficiency of small domestic booster systems. Some manufacturers may tout their small, *high* efficiency motors but, even the most efficient are just 2 - 3% better than the standard models. In the jet pump example above, a 2 - 3% increase in motor efficiency equates to just a 1% increase in wire to water efficiency.

But, even given the efficiency limitations of small motors and pumps, there are ways we can lower electrical consumption and still have water on demand. Pumps follow several invariable physical laws and, if we pay attention to them, we can use them to our advantage. Now, if you have an inverter that rivals the output of a small utility and a battery bank the size of a two car garage you can stop here. But, if you have a more typical system the following information can help minimize a booster pump's impact.

Starting Current VS Running Current

An unloaded motor, one that is spinning but doing no work, may require only a few hundred watts to keep it running. Starting that same motor from rest, however, may require several thousand watts. The amount of current required to overcome the inertia of a motor's rotor and get it spinning at its rated speed is known as starting current and is usually 5 to 10 times the amount required to keep it running. Although this *inrush* lasts for less than a second, it has a huge impact because the inverter must be capable of meeting this short term demand. Additionally, high torque machines such as elevators and conveyor belts contribute to a motors starting current. Fortunately, centrifugal booster pumps do not. Most of their pumping action does not begin until they reach full speed and, at that point, starting current demand has disappeared. There are several ways we can reduce booster pump starting current and each will be discussed a little later.

A pump motor's running current depends upon a combination of the flow and pressure produced by the pump. With centrifugal pumps, running current decreases as flow diminishes and pressure increases. It can also decrease with a decrease in motor speed. We will use these facts to our advantage later.

Low Volume Boosters

Positive displacement pumps (piston, gear, diaphragm, etc.) are hydraulically more efficient than centrifugal pumps but suffer the same motor inefficiencies. Most are not well suited for domestic booster applications. An exception is the small, cam driven triplex and quadraplex diaphragm pump. These small pumps use three or four diaphragm assemblies to push water out of the pump chamber during a single rotation of the motor. Since these individual diaphragms operate sequentially, the pulsating flow normally associated with this type of pump is greatly reduced.
115 VAC triplex an quadraplex diaphragm pumps are offered by several manufacturers and produce 2 to 4 GPM at pressures up to 40 PSI. Power requirements range from 90 to 150 watts and, while the inrush is considerably higher, it is not usually a consideration because of their small size. The diaphragm pump's lift is limited to about six feet but submersible models are available for both shallow and deep well applications.

If these flows and pressures meet your requirements, diaphragm pumps provide an inexpensive, low power alternative to jet pump systems. If the flow rate is marginal, consider installing two pumps on separate piping circuits. One could service the kitchen while another services the bathrooms. Instantaneous, gas fired water heaters can present another problem because of their minimum flow requirements. If these units are installed, a separate pump and service line may be required.

You can also install two of these pumps in parallel for a single pipe system. The secondary pump's pressure switch cut in pressure must be set a few PSI below that of the primary pump. In this configuration they will operate as a duplex lead / lag booster system and double the flow if demand requires it.

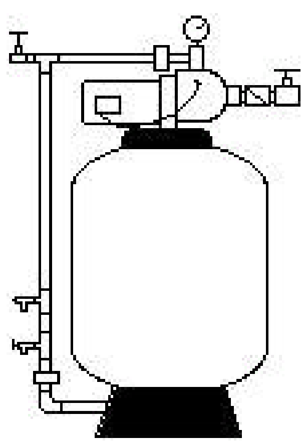
When configuring a diaphragm pump booster system always use the smallest hydropneumatic tank available. Unlike centrifugal pumps, a positive displacement pump's power consumption increases as pressure rises. Filling a large volume tank after demand ceases is not only a waste of energy but is also taxing on the pump. Remember that this particular pump was selected for its low power consumption so run it more often.

Jet Pump Boosters

The jet pump is an extremely versatile pressure booster. As I mentioned earlier, it is a centrifugal pump that recirculates a portion of the pumped water through a venturi which increases pressure at the expense of flow. 115 VAC models are available from 1/2 - 1 HP and provide flows to 20 GPM and pressures of 40 to 60 PSI. Operational power ranges from 0.9 to 1.8 kw.

Most jet pumps use NEMA Design B, capacitor start motors that incorporate a separate set of start windings and switch. This design provides high starting torque but requires a high starting current. Since the jet pump does not require a high torque motor, several newer models incorporate motors specifically designed for low starting torque applications. These PSC (permanent split capacitor) motors have a momentary inrush current that is 1/4 that of the Design B motor and are often more efficient under load. They are the best choice for inverter operation.

The Typical System



A typical pressure booster system consists of a jet pump, hydropneumatic tank, pressure switch, and check valve. When demand occurs, the pressure switch senses a pressure drop and starts the pump. When demand disappears, the pump continues to run until the tank is filled and pressure reaches shut off level. A check valve on the suction side of the pump prohibits the pressurized water from flowing back to the source. When demand reoccurs, the compressed air in the tank expands and forces water from the tank. As the tank storage is depleted pressure drops and the switch restarts the pump.

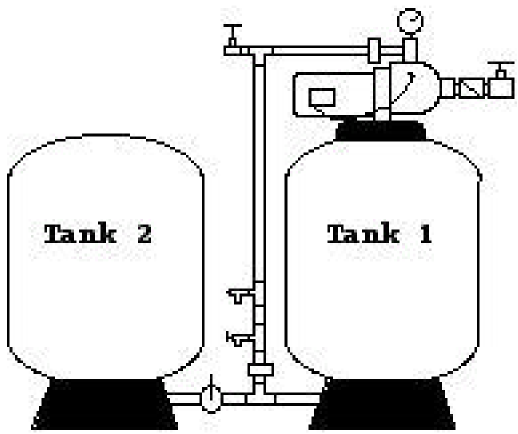
The purpose of the hydropneumatic tank is two fold. First it provides a compressible volume that allows an, otherwise, inelastic system to remain pressurized. The water stored as a result of air compression accommodates leaks and delivers a certain volume before the pump restarts. Secondly, it keeps the pump from short cycling by accommodating its output for some period after demand ceases. Tank capacity depends upon tank volume, tank air pressure, and pump start / stop pressure. Normally tanks are sized to keep pump starts to fewer than 8 per hour.

Excess Capacity Conditions

Often, conditions prevail that allow more more power to be generated than can be reasonably stored. For example, a photovoltaic system designed for year round operation will generate an excess of power during the summer months. On the other hand, wind velocity is usually greater in the winter months and hybrid systems may generate an excess during these periods. When these conditions prevail, the excess energy generated can be used to store water for usage later in the day or evening.

Excess capacity storage is as simple as adding additional hydropneumatic storage tanks in parallel. This allows the pump to run for an extended period during these opportune times. Valves can be installed so that the additional tanks can be isolated during unfavorable conditions.

At a pressure switch range of 20 PSI on and 40 PSI off, an 85 gallon tank will store 29 gallons of pressurized water. Up those conditions to 30/50 and that same tank will store 25 gallons. A 119 gallon tank will store 41 and 35 gallons respectively under the conditions above. At a 30/50 switch setting, a typical 1/2 HP jet pump will will take about four minutes to fill an 85 gallon tank and about six minutes to fill a 119 gallon tank. Multiple tank installations will require multiples of these run times.



Reducing Inverter Loading

I mentioned earlier that the PSC motor design reduces both starting current and is often more efficient under load than capacitor start models. This, ofcourse, equates to a lower inverter loading . There is, however, a way to further reduce loading of the PSC motor and also that of the capacitor start motor as well.

Although there is no such thing as a free lunch, we can control how that lunch is served. Unlike the diaphragm pump, a centrifugal pump requires less horsepower as flow decreases. For example, a pump that requires 1 HP to deliver 45 GPM @ 25 PSI requires less than 1/2 HP to deliver 15 GPM @ 35 PSI. Jet pumps follow a similar trend but the power reduction is not as great since a portion of the pumped water is always being recirculated through their venturi assembly. Still, power consumption can be reduced by 10 - 15%. So how do we implement this reduction? Very simply, just increase the pump's cut in and cut out pressure.

A typical 1/2 HP capacitor start jet pump set for 20/40 operation consumes about 0.9 kw at cut in and slowly reduces its electrical consumption to about 0.8 kw at cut out. If the pressure switch range is increased to 30/50, consumption at cut in will be about 0.8 kw and about 0.7 kw at cut out which equates to an average reduction in demand of about 100 watts.

Now I said that there is no such thing as a free lunch. What we have done is reduced demand by reducing flow. The pump will have to run longer to produce the same volume of water that it could produce at a lower pressure. Total electrical consumption will be similar for either switch setting but inverter loading will be lower at the higher setting.

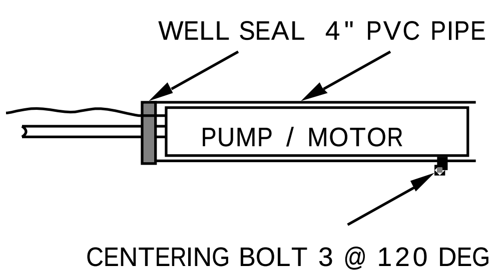
Variable Speed Boosters

Another method of reducing starting current and inverter loading is to vary motor speed. Centrifugal pumps follow a set of physical laws known as the laws of affinity. One of them states that the power required to run a pump varies as the cube of any change in speed. If one *reduces* the normal running speed of a 1 HP pump by 50%, only 1/8 HP is required to run it at the lower speed. Even a reduction of 10% results in a power reduction of 1/4 horsepower. As you can see, even fairly small speed reductions result in substantial power reductions.

An AC electric motor's speed is varied by changing the frequency of the power supply. AC power in the US is supplied at a frequency of 60 hz. With a device known as a variable frequency drive (VFD), the supply frequency can be varied 0 to 250 hz. By starting the motor at a lower frequency and ramping up to full speed over a period of a second or so, starting current is greatly reduced. Another advantage of VFD controlled pumps is that their speed can be controlled automatically to provide constant pressure during varying flow conditions. A simple pressure transducer, connected to the VFD, monitors pump discharge pressure and varies motor speed, thus maintaining pressure as demand varies. In addition to providing nearly constant pressure, the system reduces inverter loading by reducing the power required by the pump when demand decreases.

Although there are no VFD controlled jet pumps on the market, at the time of this writing, there are several 4” submersible well pump models. They utilize a high speed motor and pump (up to 6000 RPM) that offers precise pressure control at varying flow rates. Since these pumps require very low starting current and provide nearly uniform pressure, a five gallon hydropneumatic is all that is required. All require 230V so a transformer is required for inverter operation. These pumps are ideal for shallow and deep well applications and can also be used in a rainwater catchment or holding tank.

In a tank application, the pump is placed in a 4” PVC sleeve that mimics a well casing. This cools the motor by allowing water to circulate around the motor before it enters the pump. The entire assembly is then installed horizontally in a cradle that keeps it a foot or so off the bottom of the tank. From an application standpoint, it is no different than installation in a well.



Summary

As we have discovered, small booster pumps and motors are not very efficient but, there are things we can do to reduce their burden on an inverter.

1) Small diaphragm pumps offer a low power alternative if their flow rates meet the requirements of the system Also more than one can be used in a single installation.

2) When installation involves a jet pump, select one with a PSC motor in order to reduce inrush current.

3) Regardless of the motor selected, use a higher pressure switch range in order to reduce demand.

4) Add additional tankage to take advantage of excess capacity conditions.

5) Install a variable speed pump for the best possible results.

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