OPERATION OF THE LUNDELL CLAWPOLE ALTERNATOR AT HIGH POWER DENSITY AND EFFICIENCY

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ABSTRACT

The typical off grid home will often be powered by various alternative means, with solar, wind, sometimes hydro being the predominate prime sources of electrical power. In order to use these alternate source of power over the full range of a day batteries are the most common method of storage and buffering the power generated to provide for the home loads over the hours when either the wind is not blowing or the sun is not shining.

In order to assure proper charging for longer periods of time that there is no power generation available, the most common approach is that of a standby generator. Standby generators can either provide for the loads or provide for battery charging or as is most common a combination of both.

Generator systems that provide for both loads and battery charging most often use either the built in charger of the inverter system or a standalone battery charger that is simply plugged into the generator. In fewer cases the system will have a generator to provide for the loads and also an automotive alternator to do the battery charging. This paper will explore the use of both methods and illustrate the overall efficiency compared to a new approach of the "reapplication" of an automotive alternator that will be shown to operate at higher power density and with dramatically higher efficiency than either of the prior methods.

This paper will investigate if the typical automotive alternator herein referred to as the claw pole alternator can be operated at a much higher output power level and at dramatically higher efficiency. brief history of the machine will be presented, its theory of operation, what is !nown about the machine when used as designed, and what can be accomplished by changing the machines operating parameters.

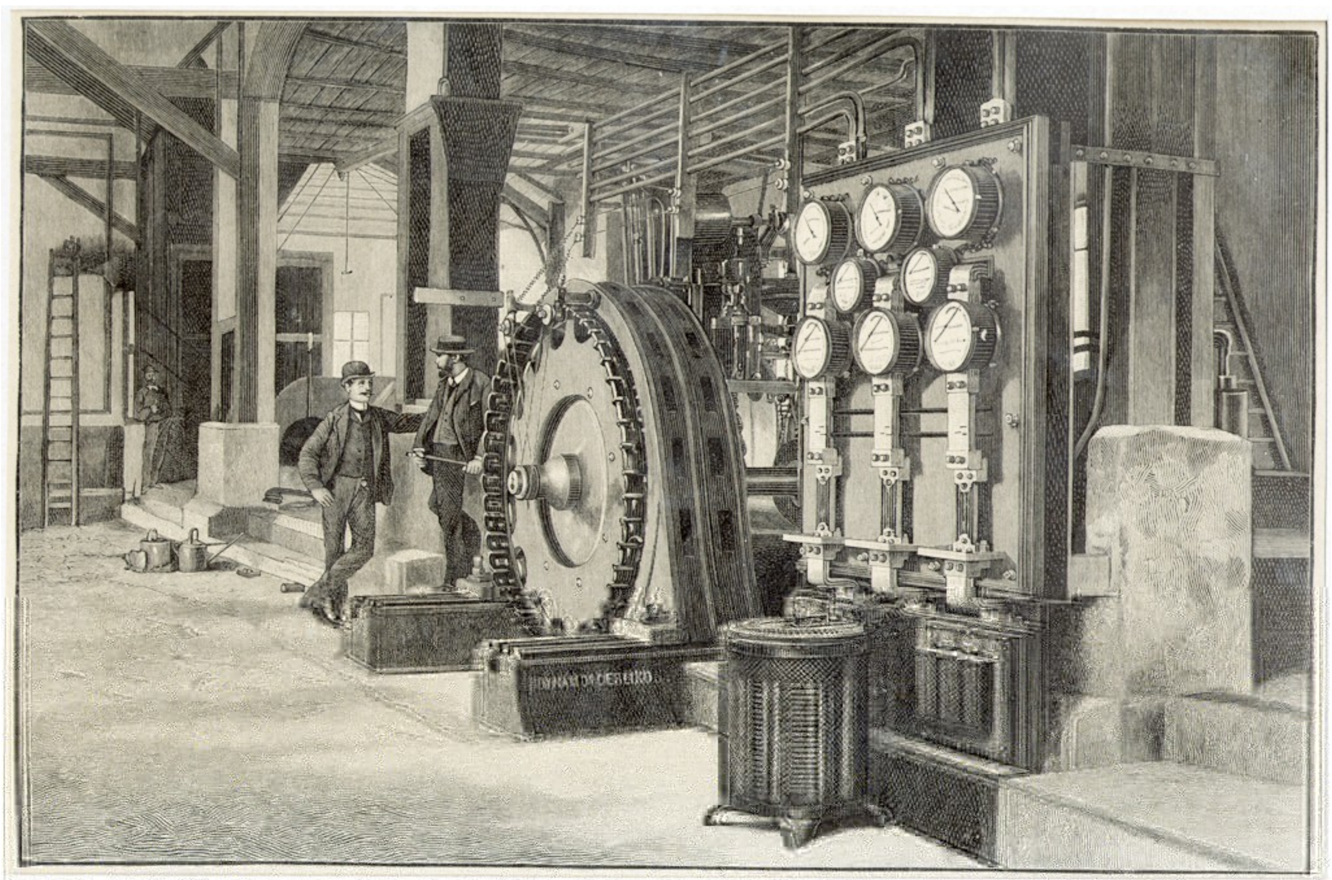
In order for the reader to fully appreciate what is presented in this paper he will need to effectively forget everything he thought he !new about the automotive alternators theory of operation, and he will need to also put out of mind any assumptions based on prior experience or what has been published by the original manufactures of the machine.

" hile the machine was built by and for the automotive industry our intended use is not concerned with the constraints place on it by that use. #or our intended purpose of charging a battery ban! at a fixed speed the machine should simply be viewed as any alternator might be, the only similarity is ***visual*** to its automotive counterpart.

HISTORY OF THE CLAWPOLE ALTERNATOR

It was always my assumption that the lundell claw pole alternator was a construct of the automotive industry, ma!ing its debut in or around $%&'. The reality is a much more interesting story in that the design predates automobiles by many years going bac! to $(%$.

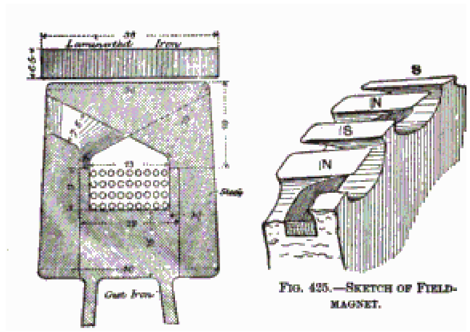
In $(%$ an alternator was demonstrated at the *“international electro-technical exhibition”* it was an alternator that was loosely based on an earlier design by mordey, however the design more closely exhibits the details of what we now call the lundell claw pole automotive alternator. This machine was designed and built by).*.+. ,rown of -urich Swit.erland at the “/erli!on "or!s”. It was the first long distance transmission of 0 phase power power in the world. ,rowns alternator had 0' poles running at $12 rpm ma!ing $322amps at 12volts per phase,, it was demonstrated to be %14 efficient.



,rown's alternator $(%$
fig. $

,rown's alternator transferred power from +auffen to #ran!furt Germany a distance of some $'1 miles. n interesting point to note is the efficiency of ,rowns lternator was within one percent of any of his contemporaries alternators at the time, and is to this day still within a couple percent of what is currently producing power for the grid. This clearly demonstrates that there was no apparent deficiency in the design.

The 6rawing and s!etch below illustrates the similarity of ,rowns alternator to the modern claw pole alternator as is typical of the automotive machine. The rotor is made up of two halves bolted over a center hub that contains the rotor field coil, and the stator is shown to be made up of laminate iron both of which were carried forth in the design by the automotive engineers some 71 years later.



6rawing and s!etch of ,rown's alternator $(%$
fig. '

)learly the ,rown alternator is the grandfather of what we now !now as the lundell alternator, so where did “lundell” come into the picture8 This is un!nown to me at this time, a 9obert +undell wor!ed for a :ew ;or!)ity based company called “*lectrical Insulation and)onduit)ompany” where in $(%$ were building 6) dynamo's and motors. t this time I am unaware of any earlier attempt at a claw pole design by either lundell or electrical insulation and conduit company prior to the successful demonstration of ,rown's machine at the $(%$ exhibition

In the mid $%12's the automotive manufactures were virtually at the end of a dead end with &volt systems and moved to $'volts, this was a stopgap measure but clearly illustrated the need for a better charging system than the generators commonly in use at the time. The late $'volt generators could not provide the power needed by automobiles that were become laden with all manner of electrical e<uipment, most of which was in itself not very efficient.)ouple that with battery technology that had not changed in 12 years and it became very clear that /*='s needed a replacement for the anti<uated charging system that was clearly not up to future power demands.

It is my assertion that the claw pole alternator was *adopted* out of all the possible designs for the following reasons.

$. It was light in weight and easy to manufacture in mass <uantity and re<uired less materials
'. It could be made to start charging well at engine idle speeds, something the generators always had issues with.
0. It could stand up to very high rpm's without destruction, and
3. It could be rectified by the relatively new silicone power diodes which would eliminate costly commutators and brushes which re<uired fre<uent service.

The automotive engineers adopted the claw pole design and basically tailored its operation to fit their intended usage. They needed an alternator that could produce roughly half of its rated capacity at engine idle and also stand up to high speed operation. In order to accomplish these goals certain compromises had to be ta!en, with the result being a unit that averages >12 4 in efficiency. This relatively low efficiency was really of little to no concern to the manufactures, they needed a good reliable charging system and gas was relatively cheap. The savings at the fuel pump that might be gained by a higher efficiency design li!ely would have been nearly unmeasurable in most cases and the mar!et at the time provided no incentive to spend a dime more than was necessary to produce a unit that would and could provide the power needed.

The claw pole automotive alternator has remained virtually unchanged for the last 12 years apart from increasing its power capability to !eep up with the ever increasing demands of modern vehicles. t present there has been much research wor! being done by the / * =5s and other 9 ? 6 labs because of concerns that the claw pole alternator has reached its maximum capability and therefore is a move to step up to the new 3'volt systems. The power density of the claw pole alternator has reached its max capability at approx $.1 @' !watts for the $'volt system.

, ecause of the enormous amount of installed manufacturing base and support for the claw pole alternator there have been several methods developed to increase the power capability of the design. It is very desirable to be able to !eep the installed manufacturing base "if" the alternators can be made to operate at higher power densities.

To date there are two primary means to increasing the claw pole alternators power density.

$. the use of transformersA this method allows the alternator to operate at a relatively high voltage and lower amperage and then using a 0phase transformer set, stepping down the output to the re<uire voltage level while increasing amperage. This method has proven to wor! however the added cost of the transformers is significant, this cost is something the / * =5s are not !een to embrace.

'. The use of a switch mode rectifier or controlled rectifierA this method allows the alternator to run at much higher voltage as in the previous example with lower amperage, and the rectifier rather than being a passive element is controlled with a pulse width modulation scheme. This wor!s by varying the onBoff time of the rectifier to control the voltage, and the scheme uses the machines internal inductance to provide for buc! converter operation. This allows the alternator to run at high voltage and low current, and the controlled rectifier as a buc! converter will lower the voltage to a regulated system voltage and increase the amperage in the process. This method is also effective, but adds expense to the system.

*ither system not only wor!s but has proven to dramatically increase the alternators typical efficiency of >12 4 to something over 72 4 .

I don5t !now which method will be adopted, but would suspect it will be a switch mode rectifier of some sort. The point of interest here as far as we are concerned is, the claw pole alternator can run at a higher efficiency than is typical today.

FACTORS THAT DICTATE THE OPERATING EFFICIENCY OF AN AUTOMOTIVE ALTERNATOR.

There are several factors that limit the efficiency of a claw pole alternator when used in an automotive application.

$. there is a need to begin charging at engine idle Calternator speed >$'22rpmD
'. there is a need for a significant portion of the full load rating to be delivered at idle
0. there is a need to deliver full power at cruise speed Calternator speed >1222rpmD
3. there is a need for the alternator to be able to drop voltage significantly under excessive loads, short circuits, etc. in order to protect itself.
1. The alternator must operate in very high underhood temperatures
&. The alternator must be reliable and low cost
7. The alternator must be able to stand up to very high speeds.

/ f these factors the most significant constraints to operating efficiency are, $, ', 0, 3, 1, and 7.

#actors $, ' and 0 relate to the need to provide large amounts of power over a very broad rpm range, and not at a specific rpm as is the case with most gen sets that run at either $(22 or 0&22rpm.

#actor 3 relates to the machines ability to protect itself against very large loads being switched on and off, fol!s Eump starting other cars, and other high current abuses that typically are not visited on gen sets. It is also well to note that while most gen sets have fuse of circuit brea!er protection the automotive alternator does not.

#actor 1 relates to the rather horrible operating conditions that the automotive alternator is as!ed to operate under. Fnderhood temperatures are often well over '22 degrees #, and there is often oil fumes, water vapor or steam if you drive over a water puddle, salt spray and all manner of dust, grit and dirt.

#actor 7 relates to the alternators ability to stand up to fre<uent excursions into the high rpm realm some are as!ed to stand up reliably to as much as (@$1!rpm.

The leaves us with #actor &, it is a testament to modern engineering when we thin! about it, that a product li!e an automotive alternator is as!ed to do what it does, as well as it does, under horrible conditions and do it well for a surprisingly long time,, and be so inexpensive as well. Is it any wonder that it should only be >12 4 efficient8 Fntil recently this level of efficiency has been a reasonable compromise.

USE OF A CLAWPOLE ALTERNATOR UNDER FIXED SPEED OPERATION

" hen the claw pole alternator is used in a fixed rpm application we eliminate much of what constrains the machine for automotive use. " e don5t need it to produce power over a wide rpm range, we can pic! a specific rpm to operate at which presumably would be matched to the output needed and at the most efficient rpm for that output voltage.

" e won5t expect the machine to operated in hostile environments, we can operated in well under the very hot temperatures that is typically the case, we can limit the fumes, gases, salt, grit and dirt as well.

" e will not be expecting the machine to be self protecting in that we can provide for over current protection, and we will not have any expectation of over speed operation as something that can happen under any but and an out of control situtation.

" e can use what the / * = builds, so there is no need to go out and reinvent the wheel so to spea!, we can use a standard G6 alternator and by application and control have it provide for any reasonable voltage commonly available today, with preference to '3 and 3(volt nominal operation.

THEORY OF OPERATION AND A LITTLE MATH:

t this point we should probably investigate what is happening inside the claw pole alternator, and what to attribute losses to. " e have the following losses to account for...

$. Stator resistance, copper is a good conductor but not perfect, the copper wire in the stator has resistance, and the more turns the higher the resistance, the higher the stator temperature the higher the resistance.

'. #ield coil resistance, the field coil is wound with copper as well and has a significant amount of resistance, however the power lost in the rotor is but a fraction of that of the stator.

0. *ddy currents and hysteresis 8core losses, these are also losses that are for the most part under the control of the designer of the machine, these losses are also <uite small compared to stator losses.

3. +ea!age inductance and reactance issues, these are dominant forces in a claw pole alternator and there are somethings here we can control by careful selection of parts and proper design.

1. " indage and #rictional losses, again smaller losses that we can5t do much about if we are going to use these machines.

&. 9ectifier losses, the silicone power diodes have a voltage drop across them of approx .7 to well over $ volt under heavy loads. The rectifier losses are not insignificant but are less so a percentage of the total at higher operating voltages, wherein a $ volt drop in a $' volt system has twice the effect of the same $ volt drop in a '3 or 3(volt system.

/ f the listed factors, stator resistance is the primary loss factor in a claw pole alternator, followed by , rectifier losses, lea!age inductance and reactance issues, then down to the lessor which is windageBfrictional losses, eddyBhysteresis core losses, and rotor resistance.

Stator losses go up with the s<uare of stator current, so an alternator that produces 12amps will have H losses attributed to it, and the same alternator running at $22amps will have (H losses. So it becomes apparent <uic!ly that the machine should be current limited to reclaim much of the loss.)utting the amperage in half e<uates to having only $B(the losses of the same alternator at full power.

/ ther losses related to lea!age reactance have a relationship to the inductance of the stator windings and the fre<uency of the machine CrpmD, the higher each goes the more lea!age reactance in the core.

There are other factors that have all sorts of e<uations to explain the various phenomena, however because we cannot easily modify many of these other factors there is little reason to discuss them in this paper.

THE IDEAL CLAWPOLE ALTERNATOR FOR SPECIFIC APPLICATION EXAMPLE

There exists vastly more $' volt alternators than there are '3volt or 3(volt alternators for use in stationary operation wor!ing at a fixed design speed, and this in many ways is a blessing in disguise.

)ertainly we can locate '3 volt automotive alternators that could be used to charge a battery ban!, what follows is an explanation as to why these alternators are not as desirable as one would first imagine for the following reasons.

$. all automotive alternators are engineeredBdesigned and manufactured to wor! in an automotive environment, having all those constraints previously described in this paper.
'. There cost is usually higher based on their relative rarity in the FS C*F countries, along with ustralia and perhaps a few others seem to have more abundance of '3volt alternators, so the premium price they get here may indeed not be the case elsewhereD
0. The '3 volt alternators will re<uire a less available regulator which is the case in the FS, but possibly not the case elsewhere as in the former example.

n explanation is in order as to why a '3volt alternator would be less desirable than a $'volt alternator for charging '3 or 3(volts.

There are two ways for an alternator to be made in a '3 volt version of a $' volt design, The first of which is the reconnection of the stator windings from delta to " ye Cstar connectedD which increases voltage by a factor of $.70 but the trade off is a reduction of amperage to >17 4 of the delta rating. This increase in voltage allows the unit to begin charging a bit higher than the $'volt version in rpm5s, but still much lower than had the machine been rewound with twice the turns on the stator.

This method wor!s, but does not materially increase either the power density or the efficiency of the alternator for our use.

The second method is to rewind the alternator using twice the turns of smaller gage wire, it must be smaller to fit twice the turns in the slots of the stator. 6oubling the turns increases the stator resistance and in doing so has a dramatic effect on stator losses. It also has an effect of roughly doubling the inductance of the stator, which has a mar!ed effect on lea!age reactance. The end result is a reduction of the amperage to about half that of the $'volt machine.

This second method returns basically the same result, while it will wor! it does nothing to increase the power density or efficiency of the machine.

This is why we need to put everything we ever learned about automotive alternators out of our mind, we need to forget all we thought we knew about automotive alternators and simply look at the claw pole alternator as simply an "alternator". There is nothing about how we are going to use the machine for our purpose that would make it useful for automotive use, and the inverse is also true. The two uses share a machine that looks alike, is built the same, but is applied and controlled very differently.

PROPER APPLICATION OF A CLAWPOLE ALTERNATOR FOR FIXED SPEED STATIONARY USE, HIGH POWER DENSITY AND HIGH EFFICIENCY

"e will now select an appropriate alternator to reapply for high output and high efficiency. The first criteria is it should be widely available, reasonably priced, very well built, serviceable, and have a proven trac! record for solid and reliable performance. The Irestolite@ +eece :eville $$2@111JG / alternator fits these criteria <uite well. It is a large frame alternator that is widely available, has a lineage going bac! to the old =otorola alternator of some 01 years ago, uses double ball brgs, has a exterior serviceable brush set, exterior piggy bac! mounted regulator, is rated at $&2amps at $'volt nominal. Gaving a $& pole rotor and stator the cut in rpm is <uite low at >(22rpms. So this unit will ma!e a suitable unit for reapplication to our purposes.

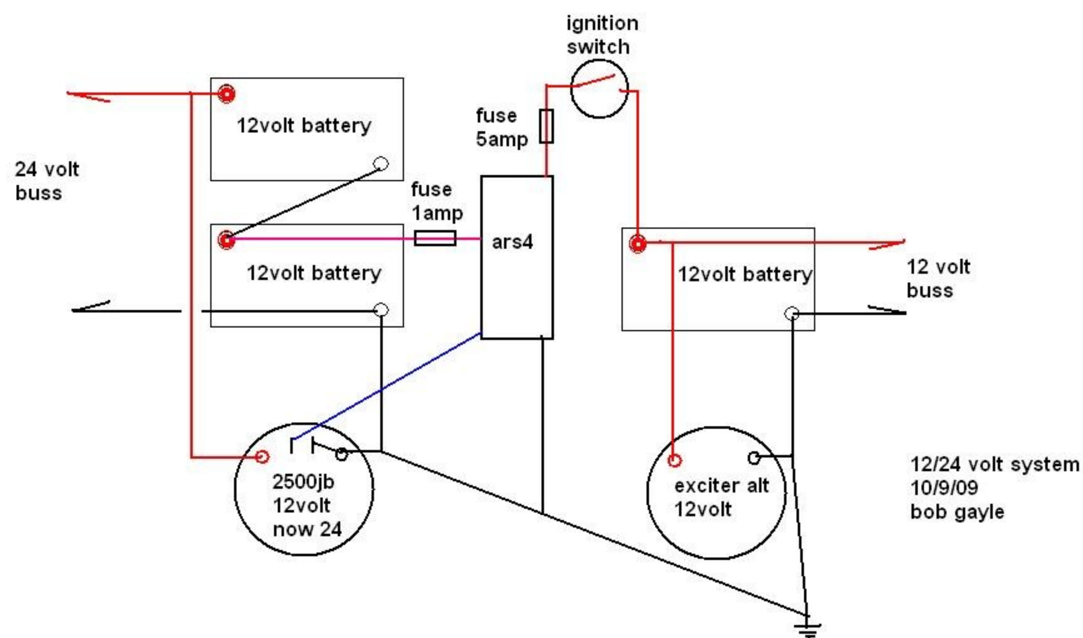
The next step is to remove the regulator, and set it aside. It being an automotive application regulator ma!es it unsuitable for use to regulate the machine for '3volt operation. This is the only change we will need to ma!e with the machine.

:ext we will adopt an architecture from the alternators big brothers, that being separate excitation of the field by a separate belt driven exciter. "e usually have a $' volt electric start on our engines, and as such must have an alternator or other charging source for charging the starting battery. This starting battery system will be the bac!bone of our excitation buss.

"e now have a $'volt excitation source for our $$2@111Eho Creapplied $'volt machineD so that if we were to turn the machine at a sufficient speed it would begin to charge. ,ecause its cut in at $'volts was approx (22rpm, its cut in speed for '3 volt operation would now be approx $&22rpm. #or reasons explained later we shall set our design speed to >3122rpm, which is well above the re<uisite $&22rpm needed for cut in at '3volts.

Such a basic system would wor! to charge a '3volt ban! “if “ one wanted to babysit a field control rheostat, but this is both ineffective and can be either inEurious to your batteries or dangerous, so
some sort of sophisticated control will be needed. " hat is needed is a regulator that can do several things that the original regulator cannot do, it must be able to be powered by a $'volt buss so as to provide power to our $'volt field, and it must be able to sense voltage at the batteries, and it must not be affected by charge algorithms of an automotive regulator but rather a much more sophisticated 0 step control. " e will explore an off the shelf solution to this re<uirement.

The ,almar =)&$' controller is a full function $'volt 0 step programmable regulator, that has many advanced features that ma!e our system not only wor!, but wor! at a higher efficiency, under tight control and have two safeties built in. The two safeties are in the form of temperature sensors one for the alternator stator and the other for the battery ban!. The former protects the alternator from overheating, and the latter sensor not only protects the batteries from thermal runaway, but allows for temperature compensation of the charging regime. It also has one other capability that we must have and that is a fully isolated sense line. The need for full isolation will be explained later in this paper.



9eapplication of claw pole alternator using
isolated excitation and field control diagram
fig. 0

THEORY OF OPERATION OF ISOLATED EXCITATION CLAWPOLE ALTERNATOR

#rom fig. 0 we can see that there are the following main components, there are two alternators, two battery ban!s, and a balmar ars3 Can earlier version of the balmar mc&$' controllerD.

The alternator and battery on the right side of the diagram are a typical $'volt system used to provide power for the engine starting system. The alternator could easily be replaced by a standard $'volt battery charger, because basically besides providing for starter power it also provides the bac!bone of our excitation buss.

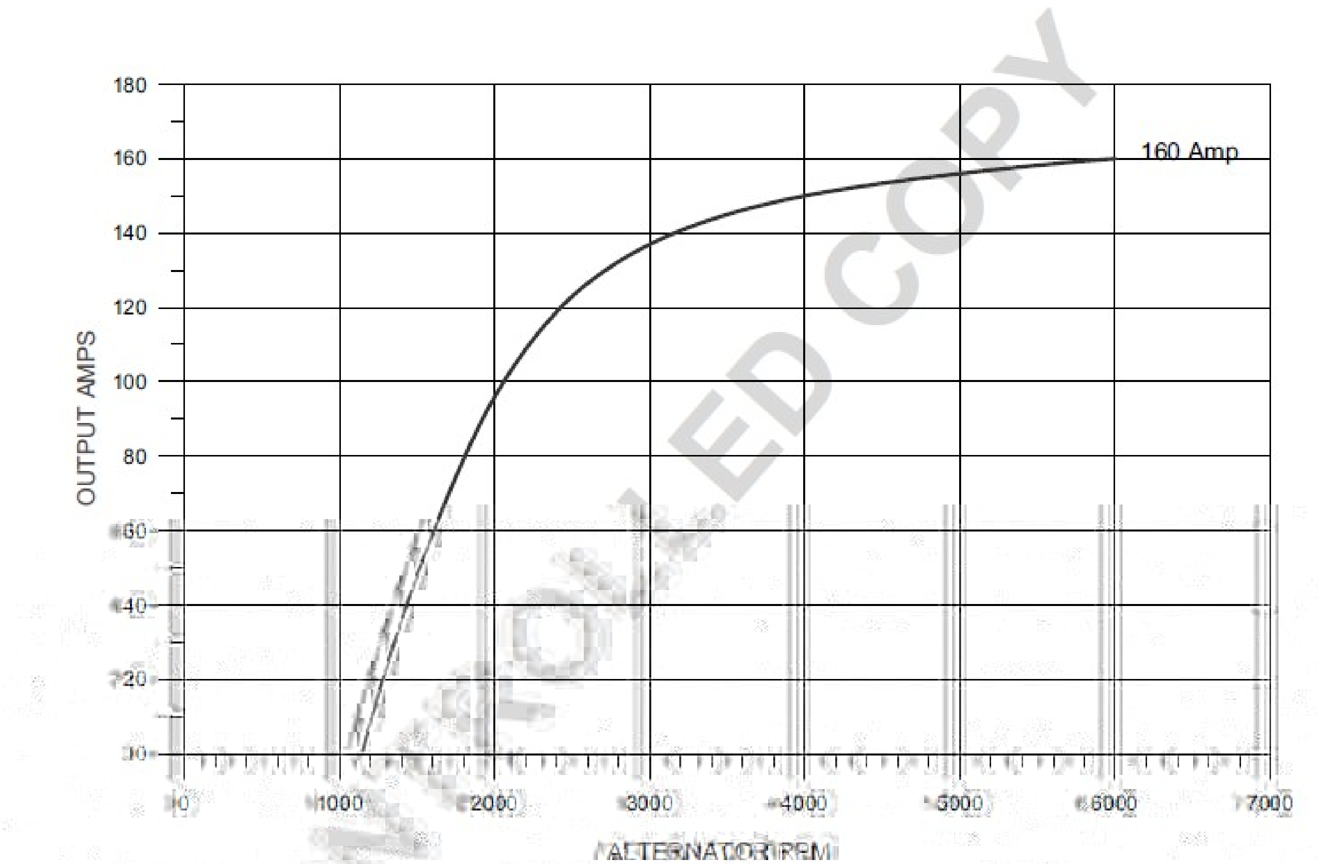
The alternator and the battery ban! on the right side of the diagram is setup to be out '3volt system, to provide power for such appliances that re<uire either '3volts or an inverter that would convert '3volts 6) to either $'2 or '32 vac at &2 h. or for '02 vac at 12h. for those that re<uire this fre<uency.

The balmar controller derives its needed $'volts from the $'volt dc buss Cright side of the diagramD and ta!es its reference voltage from mid string of the battery ban! on the '3volt system Cleft side of the diagramD. The batteries in effect form a voltage divider and provide the controllers with a $'volt sense line.

It might be as!ed why the need for a separate buss, why not Eust power the controller off the mid tap of the '3volt ban!8 ns. , ecause the controller will re<uire >1amps of power to cover its needs and that of the field of the reapplied alternator. This 1 amps will be drawn from the lower $'volt battery of the '3 volt string which would alter its voltage as compared to the upper $'volt battery causing a charging imbalance to occur over a short time. , y providing separate and isolated power for the balmar and by extension the field of the reapplied alternator no such imbalance will occur, the sense line ta!es less than $B'amp which on systems of any si.e will not present imbalance issues. In testing battery ban!s si.ed over ''1ampBhrs at '3 volts exhibit no imbalance between the upper and lower battery, as indicated by voltage readings within a couple hundredths of a volt of each other over a full charge cycle. Cin reality this difference has been witnessed to shift from one battery to the other, the end result being an even balanced charge to both batteries in the series stringD

TESTING OF THE REAPPLIED ALTERNATOR AT 24 VDC NOMINAL

/ ne of the first considerations we need to ma!e for our machine is how fast do we need to spin it8 #rom the chart in fig. 3 we see the $$2@111JG / running in its / * = designed configuration starts to charge at approximately $'22rpm for $'volts nominal. It would follow that for it to start to charge at '3volts nominal it would need to turn at approximately twice this rpm or '322rpm. Therefore it is apparent we will need to drive the alternator faster than '322rpm in order to provide charging into a '3volt battery ban!.



$$2@111JG / Irestolite power curve
fig. 3

If we loo! further up the curve we see that at approximately $22amps the output curve remains relatively linear from cut in, and then starts to brea! over and the increase in amperage re<uires a non linear addition of more rotational speed. "e also note that for the alternator to produce $22amps at $'volt nominal it has to be driven approximately $222rpm faster than cut in speed. Therefore we can assume that we need to drive the alteration at least an additional $222rpm over the baseline of '322rpm necessary to charge at '3volts nominal for a total of approximately 0322rpm.

"hat is not shown in the power graph fig. 3, is the hot curve. The hot curve is basically the power curve when the alternator is running at normal operating temperatures. "e can expect some drop in amperage running hot than the graph would indicate, so we will add more rpm to the design limit to cover for increasing heat and decreasing amperage. n additional $222rpm should be sufficient to provide for this phenomena. Therefore 0322 plus an additional $222rpm puts us at approximately 3322rpm, now we shall consider how this rpm fits in with the original design parameters of the machine.

GTTI:ABBwww.prestolite.comBliteratureBaltsBII$$0$K$$2@111.pdf

#rom the prestolite pdf we see that the machine is rated for $&2amp output at 1222rpm, and that the machine has an (! rpm continuous speed rating, as well as we !now they are typically installed in truc!s where the engine is running at '$22rpm driving the alternator at a 0to$ ratio or &022rpm. "e also !now that the alternator returns very good service life being used at this speed under very demanding conditions, so it would follow that running the unit at >3322 rpm presents no serious concerns for the machine.

,ecause of drive ratio availability on the test stand the alternator will be spinning at 3(22rpm while the engine maintains $(22rpm, needed to drive an ST7.1 generator head.

fter all connections are made as per the diagram in fig. 0, the ignition switch is turned on in order to power up the =)&$' controller. The controller is programmed for the type of batteries on the test stand, in this case a ''1ampBhr ban! of G= batteries '3volt nominal. The set point is programmed to $3.3 volts 6) Cremembering this is the mid string sample voltageD so that the total string voltage charge from the alternator will not be '(.(volts 6). "e then program for a 31 second soft start pause with another 31 second ramp up to full programmed field excitation.

The engine is then started and allowed a warm up period, followed by the activation of the controller, followed by the pause and then ramp up of excitation current to the field of the machine. "e note as the field current begins to ramp up the voltage to the battery ban! begins to rise as well as the amperage, topping out at '(.(volts as predicted and the current is approaching $'2amps. "e note no unusual smo!e from the engine owing to the soft start feature.

"e go bac! into the controllers program screen to activate a very useful feature that sets this controller apart from any standard regulator, that being what balmar refers to as the “amp manager” ,y altering this set point we can tailor the amperage output from the alternator to Eust where we want it for our testing, which is $22amps max output. This feature is <uite useful in that had we miss applied our drive ratio or had an engine that was too small in horse power to drive the load we could simply adEust the amp manager to tailer the output to match the available power.

In further testing we allow the engine to come up to temperature and stabili.e at '22 degree5s # "e apply inverter loads and resistance heaters to maintain our $22amp load on the alternator and monitor the voltage and note it staying right on '(.(vdc. "e measure the lower battery and find it to be sitting right on $3.3 as does the upper battery which e<uates to the batteries being charged e<ually. Cwe note there is some fluctuation of .2'@.20 volts shifting from the upper to the lower and visa versaD

The alternator stabili.es with a stator temperature of $71 degree5s #. which is well below the operating temp of the /*= spec5s of ''2 degree5s #.

Testing results

The machine has proven to be reliable and stable producing '(.(volts 6) at $22amps output for a total of '.((!watts. The original parameters for this alternator is $3.' volts 6) at $02amps hot for a total of $.(1 !watts. This is an increase in output power of 11.7 4

/ f note, the field power at this output level remained at approximately 0& watts throughout testing at the $22amp level.

#urther testing returned the machines ability to run at '(.(volts 6) at $02amps for a total of 0.73 !watts, which e<uates to an increase over the original design parameter of '2'.' 4. "e did not pursue testing at this level because of having the alternator turning in the opposite direction of the directional fan that came with our original unit, and the concern for thermal runaway due to insufficient cooling airflow. bidirectional fan is available for machines up to $32amps of this family of alternator, one of which will be used in future tests.

"e have now witnessed one of our initial criteria coming to fruition, that being the increase of the machines power density operating at other than its original designed voltage. The next series of tests revolve around the efficiency of the alternator operating under these conditions.

The test stand is comprised of a changfa S$%1 I6I diesel engine, it direct drives an ST7.1 at $(22rpm, it also drives twin alternators C$$2@111JG / D one of which provides for starting battery charging and for the excitation buss current, the other is the reapplied alternator that is being tested for use at '3volts nominal.

"hen all testing is done all driven units are being driven and are either being tested or form parasitic loads, this ma!es for the elimination of drives and other component losses that might s!ew test results from one unit to another. In this setup we cannot determine exact efficiency but we can determine relative efficiency to very accurate numbers. "e can determine exactly how many grams of fuel the engine consumes per !wattBhr when ta!ing power off the ST 7.1 and we can also determine the exact amount of fuel that the reapplied alternator consumes per !wattBhr as well.

It is the difference in gramsB!wattBhr between the two units Cst7.1 vs $$2@111D that will indicate to us whether we have an increase in efficiency over the baseline of the / * = alternator operating under original design parameters.

"hat we found in numerous tests over several days , operating at various load levels was the reapplied alternator mirrored the fuel consumption of the ST7.1 gen head. , ecause no specific efficiency data exists or at least is !now to me for the ST generator heads I can only surmise mathematically that it is approximately 7(@(2 4 efficient. This would indicate from a relative viewpoint that the reapplied alternator is now running at this same calculated efficiency. This is a dramatic improvement over the / * = design parameter of approx 13 4 efficiency for this alternator running at $' volts nominal. This e<uates to an increase in efficiency of approximately 33.3 4 Cfrom 13 to 7(4 is an increase of 33.3 4 D

"e can now conclude that the reapplication of this alternator from $' volts to '3volts nominal is not only possible but results in a dramatic increase in power density C >11 4 to as much as '22 4 with proper coolingD and an e<ually impressive gain in efficiency of approximately 33 4 .

Conclusion

/ver the course of this paper we have followed the progression of the claw pole alternator from its inception nearly $'2 years ago, through is adoption by the automotive industry, toward its modification for use with the new 3' volt standard, and finally with its reapplication for a specific use charging a battery ban! in a controlled manner at higher voltages, power densities and efficiency.

It should be obvious that the original design as implemented by).*.+. ,rown of the /erli!on wor!s for the exhibition in $(%$ +auffen to #ran!furt transmission of 0 phase power over a long distance at better than %34 efficiency there is nothing inherently wrong with the design. 9ather its simplicity lead to its adoption by the automotive industry where it has been pressed into service producing power under rather extreme conditions over a very broad rpm range, with efficiency concerns not even entering the e<uations until very recently.

"e have explored the factors limiting output and efficiency of the claw pole alternator as used for automotive applications and how many of these limitations or factors that constrain the alternators use for our purposes can be avoided. The results have proven that the automotive alternator as tested can be reapplied in a very specific manner to do what we need it to do at a much higher power density and efficiency.

"hile this may be of little concern to many installations where battery ban! charging is a small part of an overall system, it should be of much greater concern to those installations where battery ban! charging re<uires a significant amount of engine run time. ny installation that has a large installed base of batteries to maintain, that are moderately cycled with regular fre<uency that re<uires the use of an engine driven gen set for recharge stand the most to be gained from increased overall efficiency where these increases e<uate to a reduction in fuel consumption, reductions in engine runtime, along with extended engine lifespan and its maintenance.

There can be little argument to support the use of a charger being simply plugged into a generator head or the use of an inverterBcharger to do serious battery charging wherein the overall efficiency will be mar!edly lower than the system described in this paper. =ost especially when it is considered that the engine rpm can be tapered bac! as the charge rate reduces, which will also reduce the fuel consumption and increase engine service intervals and life. Tapering bac! engine rpm of an engine driven) generator is not generally possible without a significant control scheme and a charging system that can ta!e a lower fre<uency power as a result.

It should also be noted by the reader that this proEect is a first step in optimi.ation of a claw pole alternator. "hile further increases in efficiency may be possible they are li!ely to be found at higher generated voltages such as 3(, &2 or even higher levels.

Those interested in wor!ing with this method should note that alternators that are built on the same frame but various configurations have the highest li!elihood for success. Through careful selection of off the shelf parts very high power levels can be attained.

s of this writing a 0rd generation unit is in the process of being tested that appears to have an exceptionally high power density of over 7!watts at 17.& volts 6). The efficiency in theory should brea! into the low (2's 4, time will tell and much more wor! needs to be done.

SOURCES / INFORMATION

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(WO/2000/048303) Altnerator system with transformers and ac-dc converters

patent papers relating to the use of 0 phase transformers and automotive alternators, with) to 6) converters