Building a Fuel Efficient Electrical Generator Using Continuously Varying Transmission

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Abstract —*To produce 220 V AC at 60Hz, the genset engine has to keep a steady RPM of 1800. This speed must be maintained even if there is no load or extremely less load on the alternator, thus making the system inefficient in idling condition. This paper presents a solution for decreasing the fuel consumption of gensets and utilizing their engine torque to the best possible extent. Also, the paper presents a solution to how an engine can produce more power than rated in emergency situations.*

Index Terms —Power generation, AC generators, Gears.

I. INTRODUCTION

Regardless of size, generators running on petroleum fuels such as diesel, natural gas and gasoline have a standard configuration; where an internal combustion engine is the prime mover and turns the alternator shaft. The crank shaft, that is the output of the engine is directly coupled to the alternator shaft. In a no load condition or in a condition where no significant load is applied on the genset output, the engine still runs at the standard 1800 RPM. If the engine is slowed down to save fuel, the RPM would reduce causing the output voltage to lower down. This situation, where we want our output RPM to stay constant but reduce engine speed for fuel economy can be solved by incorporating an automatic gear box in the genset.

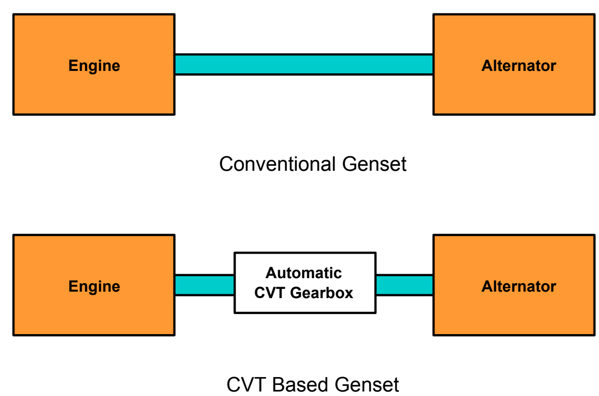

Fig. 1. A conventional genset and a CVT based genset

This gear mechanism would work on the same principle like it does in a car, i.e. interconversion of torque and speed. The basic idea is to automatically adjust the speed and the gear ratio of the system to find a "sweet point" where fuel consumption is least.

Section II of the paper will describe the conventional mechanism of a genset. Section III will introduce the mechanical concepts of continuously varying transmission. A proposed design of a CVT based genset will be presented in Section IV and finally the design of a control unit for this genset will be presented in Section V.

II. CONVENTIONAL GENSET MECHANISMS

Engine-Generators also called gensets are used all over the world for standalone and parallel power production. In third world where there is an increasing power shortage, small models of gensets having 1-5 KVA output are gaining popularity. These gensets also inherit the same problems of inefficiency at idling condition or when load is not significant. All gensets use a standard governor. Governor changes the power of the engine depending upon the mode then genset is running in. In power plants where parallel generators are connected to each other, droop settings[1] are used, where as in standalone isolated generators, usually used for office or home, it uses the isochronous mode where the engine speed is changed using frequency or speed as feedback. Frequency and speed are directory proportional to each other and either of them can be used for this purpose. Thus, as the load increases on the genset, the speed and the frequency of the alternator decreases. Because the engine shaft (driving shaft) and the alternator shaft (driven shaft) are both directly connected, a minimum speed of 1800 RPM must be maintained (considering that a 4 pole alternator is used) by the engine at all time, whether there is load on the alternator or not. Small home/office generators usually have negligible loads such as energy saver tubes for which the fuel input to the engine is already way beyond its requirement. Once load is increased and a threshold point is reached where the existing engine power becomes insufficient to maintain the 1800 RPM mark, the governor changes the fuel input settings and delivers more fuel to the engine, resulting in higher torque output.

III. CONCEPT OF CVT

The basic idea of this paper is decreasing the engine RPM for saving fuel and compensating the RPM by a gearbox – that is, engine is supplied with less fuel but consequently the RPM decreases and this decreased RPM will produce low frequency alternating current. To tackle this problem, a gearbox must be utilized to speed up the output shaft and maintain it at 1800 RPM. The conventional gearbox like what is utilized in a manual transmission car cannot be used because it has finite number of gear ratios, where in this case, theoretically infinite number of gear ratios are required to compensate infinite possibilities of engine speed.

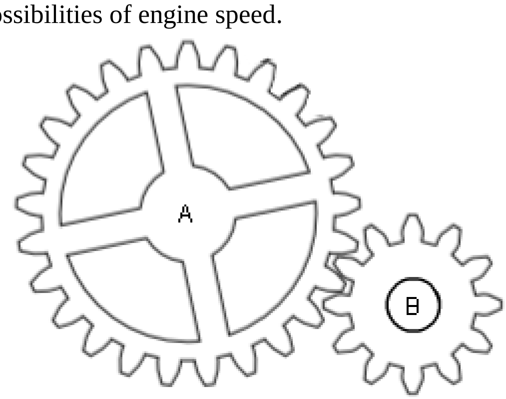

Fig. 2. Two gears having gear ratio 0.48:1

In figure 2, two gears are shown having different number of teeth. Gear A has 25 teeth and gear B has 12 teeth. If we consider that gear A is being driven by an engine and gear B is attached to the alternator shaft, 0.48 turns of gear A will give one complete rotation to gear B, hence the gear ratio [2] is 0.48:1 Therefore, a slow engine driving gear A at 864 RPM will drive an alternator attached to gear B at 1800 RPM.

Although, the gear system described above is the basis of how to increase output speed, but it cannot be utilized in a genset where load is uncertain and changing. As load on the alternator can have any possible value, the gear ratio and engine speed have to be varied precisely to find the "sweet point" where the gear ratio can give maximum support and keep the engine at the lowest possible RPM. So, having a few fixed and discrete gear ratios is not useful.

Continuously Variable Transmission is a mechanical arrangement that has no gear step and theoretically provides infinite gear ratios to the system between two fixed limits.

The CVT mechanism used in this paper is traction based[3], in which two cones, or wheels rotate each other by friction and no belts are involved. The gear ratio is changed by changing the angle or position of wheels/cones.

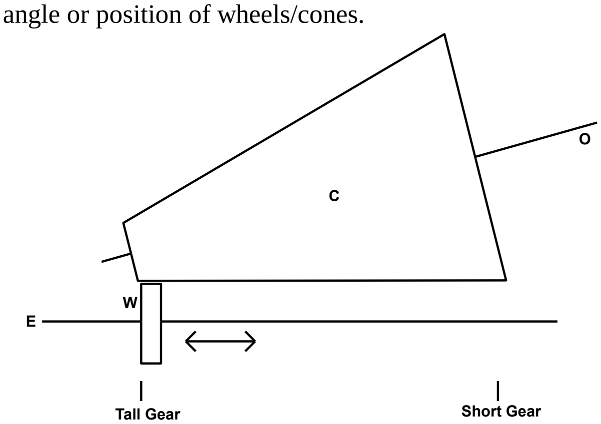

Fig. 3. A traction based CVT in tall gear

Figure 3 shows the basic construction of a CVT that is utilized in the design of genset in this paper. Shaft 'E' is being rotated by engine. It has a wheel 'W' attached to it that rotates at the speed of the shaft 'E'. This wheel has contact with the cone 'C' which rotates along with its shaft 'O'. This output shaft 'O' is connected to the alternator. It is clear from the diagram that when the wheel touches the cone at its end with minimum diameter, a tall gear is created, that is, one rotation of 'W' will produce many rotations of 'C' giving us higher output speed but reduced torque. This is similar to the gear action of Figure 2, but this time utilizing a CVT.

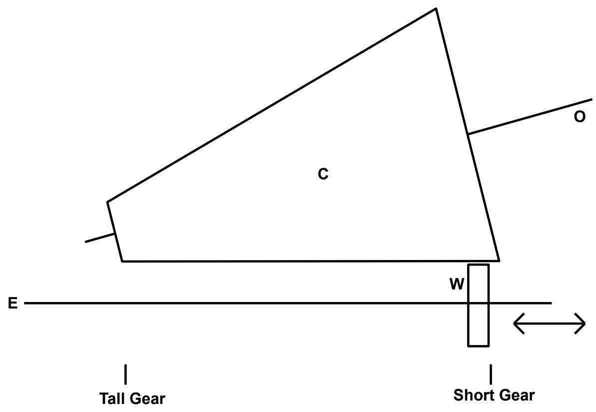

Fig. 4. A traction based CVT in short gear

Here, in figure 4, the same wheel has been moved to a point on the x-axis where moves a larger diameter of the cone. On this case, many revolutions of 'W' will make one revolution of 'C'. Hence, here the torque is being amplified and speed reduced. Both ends of the output shaft 'O' and engine shaft 'E' are supported by ball bearings. Because there are no belts involved, this traction based CVT performs better than conventional belt CVTs that are prone to slip. This CVT can be built into a very small hull.

IV. DESIGN OF A CVT GENSET

Engines can usually operate at 25% higher RPMs with no damage. It means more power can be fetched from an alternator than rated. The limitation in achieving this goal is that engine RPM would be higher and output frequency would increase. CVT also answers this problem by giving us a short gear mode in which more torque can be delivered to alternator while still maintaining 1800 RPM. Therefore the design of the CVT for the genset must satisfy a gear ratio that produces output speed of 1800 RPM when engine is idling at 800 RPM and also produce 1800 RPM when engine is working at 125% rated RPM of 2250.

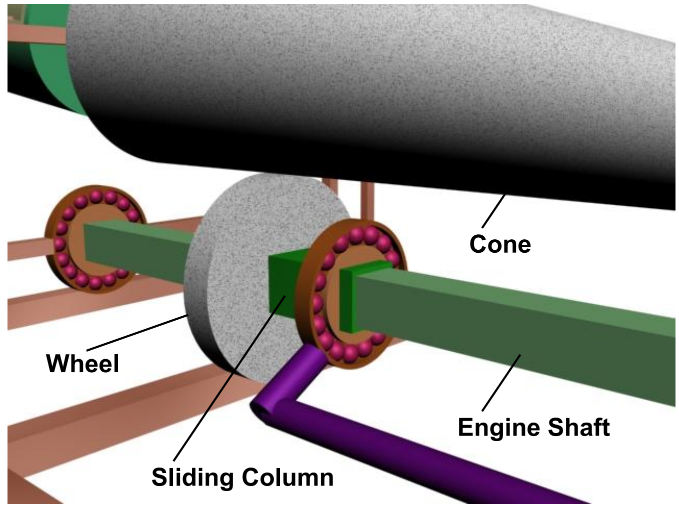

Fig. 5. Three dimensional view of wheel cone mechanism

Hence, the minimum diameter of cone is set to 2.64 cm and maximum diameter is set to 7.5 cm. the wheel connected to the engine shaft has a diameter of 6 cm. Therefore, for this system infinite gear ratios can be obtained between extremes gear ratios of 0.44:1 and 1.25:1

Figure 5 shows how the wheel is moved along x-axis relative to the cone. The wheel rides a sliding column which slides on the main engine shaft. The whole "Wheel-Sliding column" assembly is linearly moved by rack and pinion mechanism powered by encoder based DC motor. Internal side of the ball bearing is fixed with the assembly and the outer is attached to the rack and pinion mechanism. Therefore the whole assembly can be easily moved along x-axis at high rotational speeds.

Conventional governor is replaced by a sophisticated transmission control unit that is discussed in Section V. The control system sends commands to servo motor that utilizes a crank mechanism to control the position of the throttle. Therefore the amount of fuel going into the engine is controlled electronically by the servo motor. Figure 6 shows a servo controlled mechanism that changes throttle position.

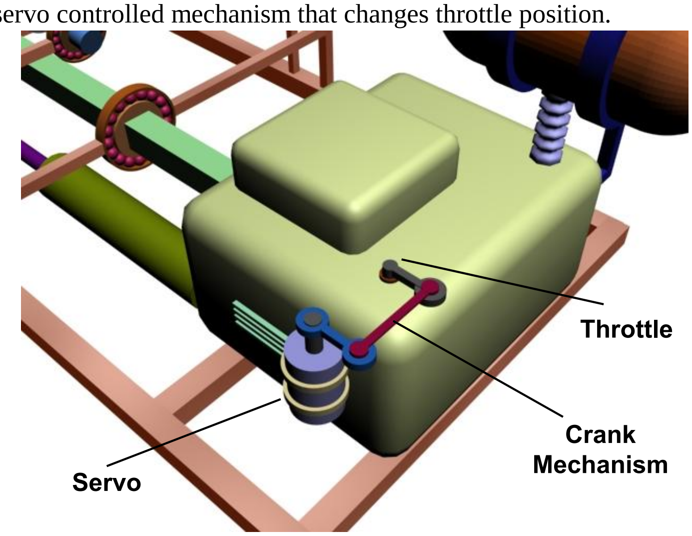

Fig. 6. Servo throttle control utilizing crank mechanism

An accurate and cost effective system is thus designed that can be plugged with most of the conventional engine control units. This system is vendor independent and can virtually be the total kilometers driven using those 200 bars of gas. This method is also not reliable as the driver cannot be sure how much compressed gas was put into the cylinder when it was “topped up”. If the

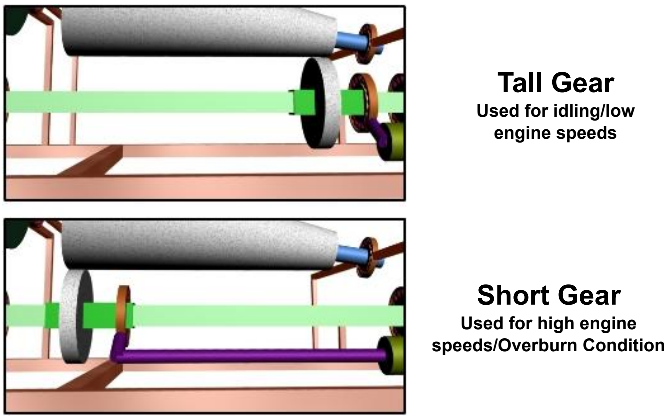

Fig. 7. Short and Tall gear Selection on traction CVT

Figure 7 shows the two extreme position of the wheel along x-axis driving the output cone.

V. TRANSMISSION CONTROL UNIT FOR CVT GENSET

The transmission control unit for CVT based genset has frequency as its feedback parameter because the genset is considered to be in isochronous mode. A frequency of 60Hz is to be mainlined, for which the transmission control unit will find the correct engine speed and gear ratio and set them accordingly. At the boot up, the transmission control unit will select the gear ratio variator to its maximum value i.e. the shortest gear possible. This is done as a precaution that the load at startup might be too high.

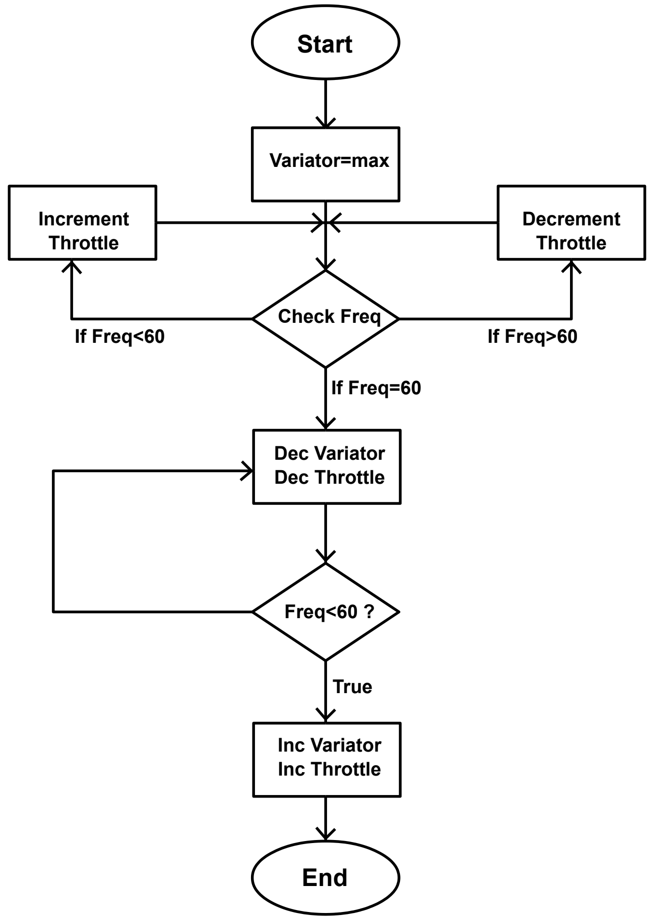

Fig. 8. CVT based genset boot-up sequence

Then, throttle position is adjusted so that 60Hz frequency is achieved. Now, the system tries to decrease both gear ratio variator value (to go towards a taller gear) and throttle value. This decrement is continued until the system detects that frequency drops below 60Hz. It indicates that the system needs one step correction in the opposite direction i.e. Increasing both throttle and gear ratio variator values by one point. At this point, the “sweet point” for that system has been achieved and the genset is working on the lowest possible fuel.

After successfully booting up, the transmission control unit starts another algorithm that checks whether the load is increasing or decreasing on the alternator. The increasing or decreasing frequency feedback is used to adjust both throttle position as well as gear ratio variator. In the running more a threshold frequency F_T is used. Threshold is the frequency difference between 60Hz and the current frequency. It is used to prevent over correction by which the system might get overwhelmed. A correction in fuel intake/gear ratio is made only when the threshold if reached.

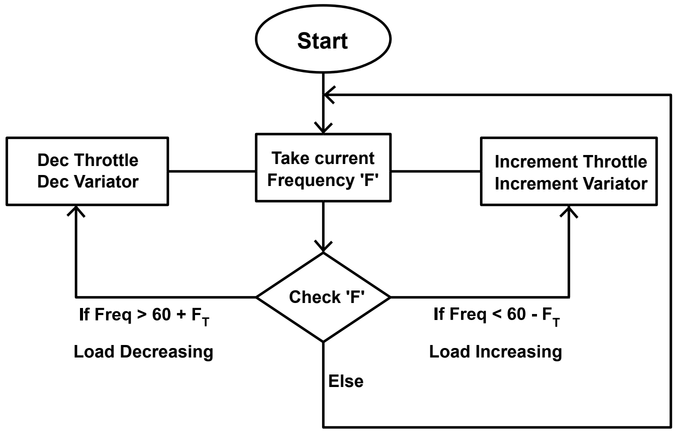

Fig. 9. CVT based genset running mode algorithm

CONCLUSION

A system is thus produced that can produce electricity at cheaper cost, producing less noise, increasing engine life and is environment friendly.

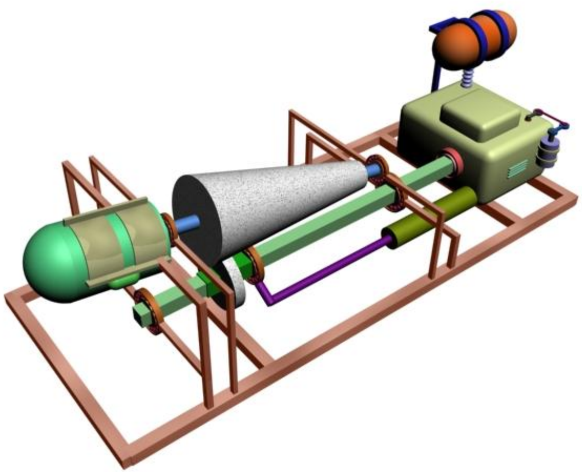

Fig. 10. An overall 3D view of the CVT based genset

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