Design and Implementation of an Adaptive Electronic Speed Governor

ABD. UL. KAREEM. M. OBAIS   Qais Kareem Omran   Hussain Fadhel Hamdan
College of Engineering / University of Babylon

Abstract

In this paper the role of the speed governor and some of its techniques are reviewed. The adopted governor is an electronic speed governor based mainly on analogue computations. Here the speed of the prime mover is governed by an analogue signal extracted from the real frequency of the voltage generated by the coupled alternator. The implemented system senses frequencies in the range of ±10% of the nominal frequency (f_o) of the generated voltage and tends to fix the frequency of the generated voltage at f_o.

The system is identified by a fast and controllable response. The associated errors of the whole system are almost negligible.

الخلاصة

في هذا البحث تم تناول دور حاكم السرعة ومراجعة بعض التقنيات المستخدمة في هذا المجال. حاكم السرعة المتبنى في هذا البحث هو حاكم سرعة الكتروني يعتمد اساساً على الحسابات الالكترونية التماثلية، حيث يتم التحكم في سرعة المحرك الاولي بأستخدام اشارة تماثلية مستخلصة من التردد الحقيقي للفولتية المتولدة من المولد المقترن مباشرة بالمحرك الاولي. النظام المنفذ يتحسس للترددات ضمن المدى ±10% من التردد الاساسي (f_o) للفولتية المتولدة وبعد ذلك يتجه الى تثبيت التردد ضمن حدود (f_o).

يمتاز النظام المنفذ بأستجابة سريعة ومسيطر عليها. الاخطاء المرافقة لتنفيذ النظام بأكمله هي مهملة في اغلب الاحيان.

Introduction

The electrical real power is adjusted by the automatic control system according to the deviation occurs in turbine speeds or power system frequencies. Here the speed governors play a great role on system stability. When the electrical load is suddenly increased, the kinetic energy stored in the prime mover is not sufficient to satisfy the increase in electrical power demand; hence this reduction in kinetic energy available in the turbine leads the turbine speed and system frequency to fall. This change in turbine speed is sensed by the turbine governor which in turn adjusts the turbine fuel valve in such away that the mechanical power of the turbine will be increased to the value sufficient to treat the reduction in system frequency [Gamal et al 2004]. When the electrical load is removed suddenly, the turbine governor tends to close the turbine fuel valve in such away that a suitable reduction in kinetic energy of the turbine will take place [Marra et al 2000, Schulte 2000, Henderson 1993, Alghuwainem 1997].

One type of speed governor was the watt governor which detects the speed by rotating flyballs and provides mechanical levers motion in response to the speed change [Gamal et al 2004]. The automation of the above governor is achieved mechanically. Since the change in electrical load causes deviation in turbine speed and consequently a change in system frequency, the change in frequency is employed as the main controlling signal in our approach concerning the design and implementation of a new adaptive electronic speed governor. Fig. (1) shows the block diagram of this governor. Here the

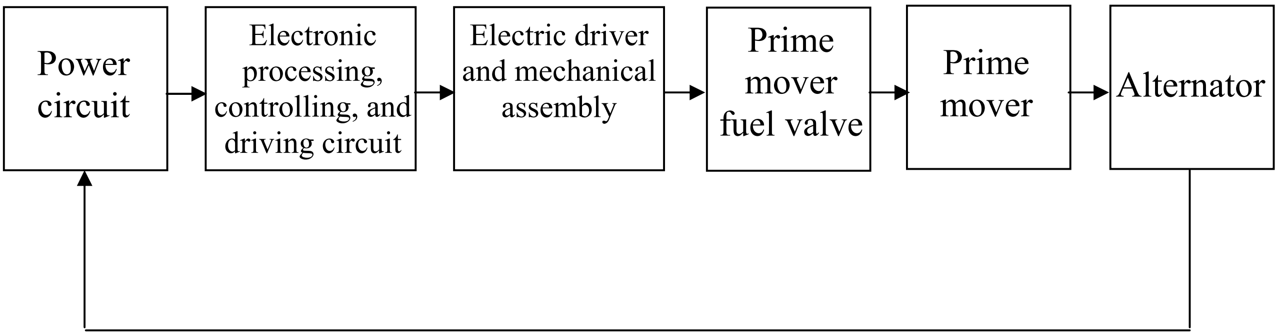


Fig.(1) The new electronic governor concept

output voltage of the alternator is fed to the power circuit which in turn provides the required DC voltage to the whole system. The next circuit is the electronic processing, controlling and driving circuit which extracts the change in the frequency of the output voltage and generates the required driving signal to the electric driver. The electric driver with its mechanical assembly tends to move the fuel valve of the prime mover toward the direction that achieves the suitable correction for the voltage frequency.

The governor system scheme:

This governor is designed in such away that will respond to any change in the frequency of the generated voltage of the alternator. The change in the frequency of the generated voltage will be translated to a controlling signal which is exerted upon a driving circuitry governing the fuel valve. If the generated voltage frequency exceeds the nominal frequency, the controlling signal will be in a status that tends to reduce the fuel valve hollow, such that the prime mover speed will be reduced. Consequently the frequency of the generated voltage will be reduced too till the nominal frequency is reached. The response of the system is determined according to the prime mover features used in the system. The same manner will be accomplished for a reduction in the generated frequency. In this case the controlling signal will tend to increase the fuel valve hollow of the prime mover.

Fig.(2) shows the governor system scheme. Here the step down voltage transformer is connected directly to the alternator voltage terminals. Its output is a low voltage suitable for the operation of the electronic circuit. A DC stabilizer is designed here to produce the DC voltage necessary to operate the whole governor circuitry. The AC output of the step down transformer is fed to the waveforms generation circuit which is in turn produces the necessary waveforms for operating the next computation circuit and the controlling circuit. For example the waveforms in point B is rectangular and is a result of a zero crossing detection of the sinusoidal output of the step down transformer. The waveforms at points D and E are two out of phase saw tooth waveforms of a frequency which is twice the frequency of the alternator terminal voltage. The rectangular waveform of the zero crossing detector is fed to the computation circuit. The first step of the computation circuit is a simple differentiator which produces a negative voltage for triggering a mono-stable of a time constant of τ. The time constant value is computed to be 0.9 T_o .Where T_o the time period of the alternator voltage at its nominal frequency f_o. The above value of τ allows a linear detection for the frequency of the alternator voltage in the range of $0.9f_o \leq f \leq 1.1f_o$.

For example when the actual frequency f is 1.1 f_o then the output of the mono-stable will be a continuous DC voltage, hence the output of the DC filter will be the same output of the mono-stable which is equal to 5V. When f is $0.9f_o$ the output of the mono-stable will decrease and its average value is 4V and hence the output of the DC filter will be a DC voltage of 4V. When $f=f_o$ the output of the DC filter is 4.5V. The output of the DC filter is buffered and fed to the controlling circuit namely to the difference amplifier. This DC voltage is compared with a DC reference voltage proportional to the nominal frequency f_o , and is of a value of 4.5V. If the actual frequency is above f_o, then the DC voltage in point I will be greater than 4.5V and hence the difference amplifier output at point J will be positive. The output of the difference amplifier is fed to the response decision amplifier which is in turn a variable gain inverting amplifier. Hence when $f > f_o$ the output at point K is a negative voltage and vice versa. When $f > f_o$ the output of comparator (1) is logic ZERO at point L and logic ONE at point M. The negative voltage at point K is compared in comparator (2) with a negative saw tooth coming from point D. Consequently the output of comparator (1) at point N is a rectangular waveform which is in turn anded with the logic ONE at point M. The output of the AND gate(1) is the triggering signal to the driving circuit which is tending to decrease the hollow of the fuel valve. Note that the output of the comparator (3) is ZERO, hence AND gate (2) is logic ZERO.

When $f < f_o$ the voltage at point K is a positive DC voltage and the output of comparator (1) is logic ONE at L and ZERO at M. The output of comparator (2) is ZERO and AND gate (1) is logic ZERO, while the output of comparator (3) is a rectangular waveform at point O and is anded with logic ONE at point L. The output of the AND gate (2) is triggering the driving circuit in such a manner that it is tending to increase the fuel valve hollow.

The electric driver is operating a mechanical assembly governing the fuel valve of the prime mover. The response of the governor is determined by the response decision amplifier.

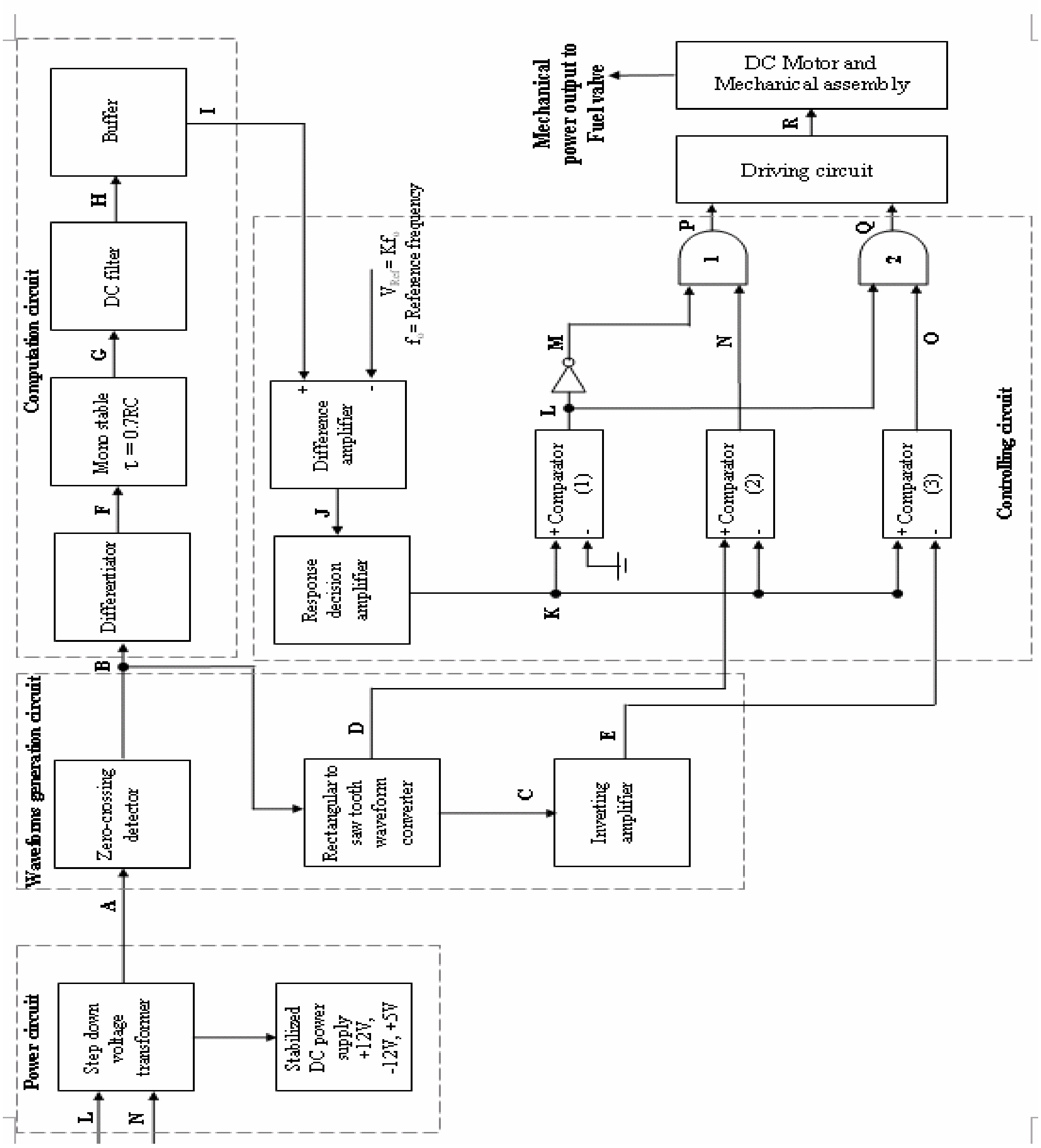
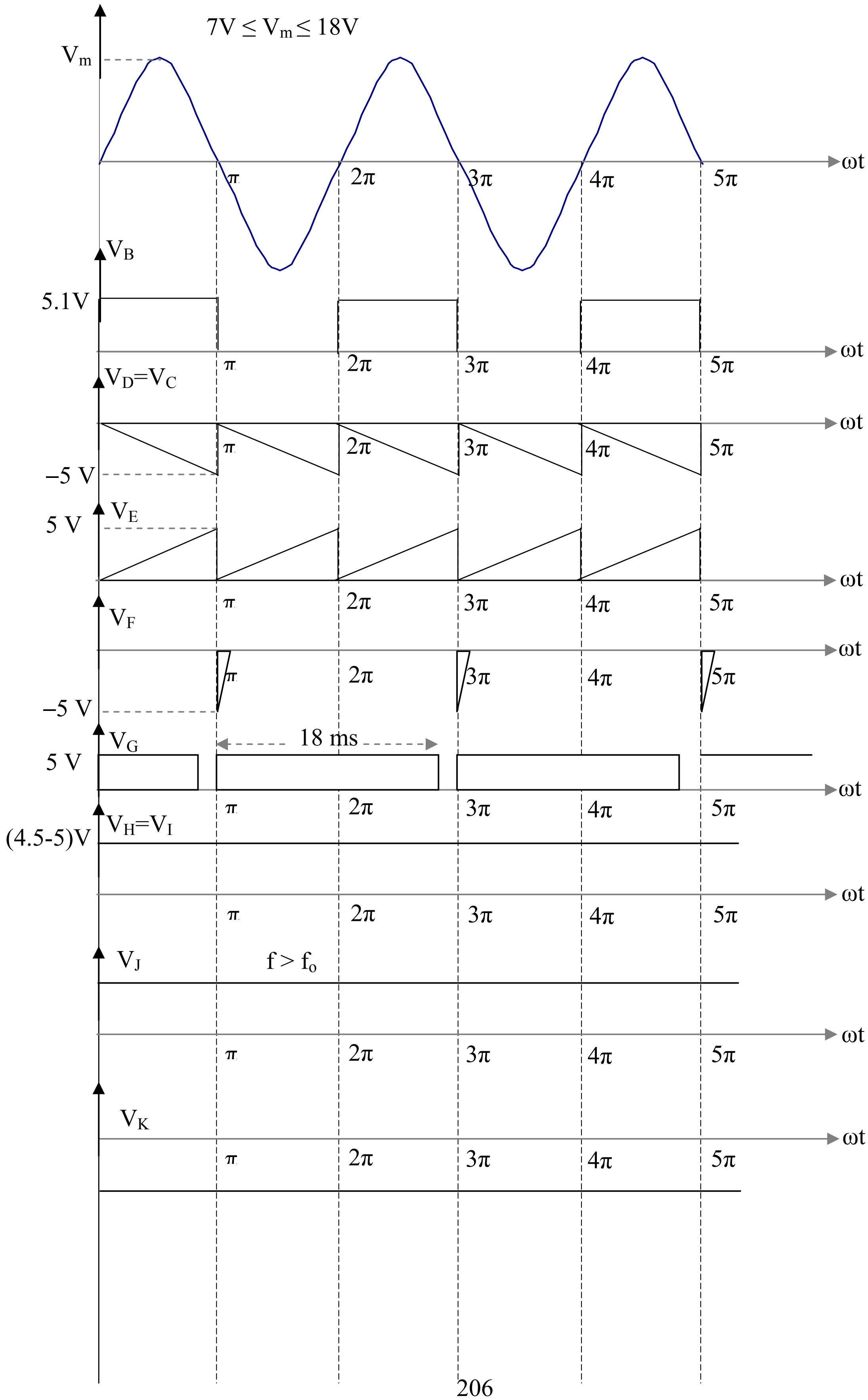


Fig.(2) The governor system scheme



7V ≤ Vm ≤ 18V
Vm
ωt
π
2π
3π
4π
5π
VB
5.1V
VD=VC
−5 V
VE
5 V
VF
VG
18 ms
VH=VI
(4.5-5)V
VJ
f > fo
VK

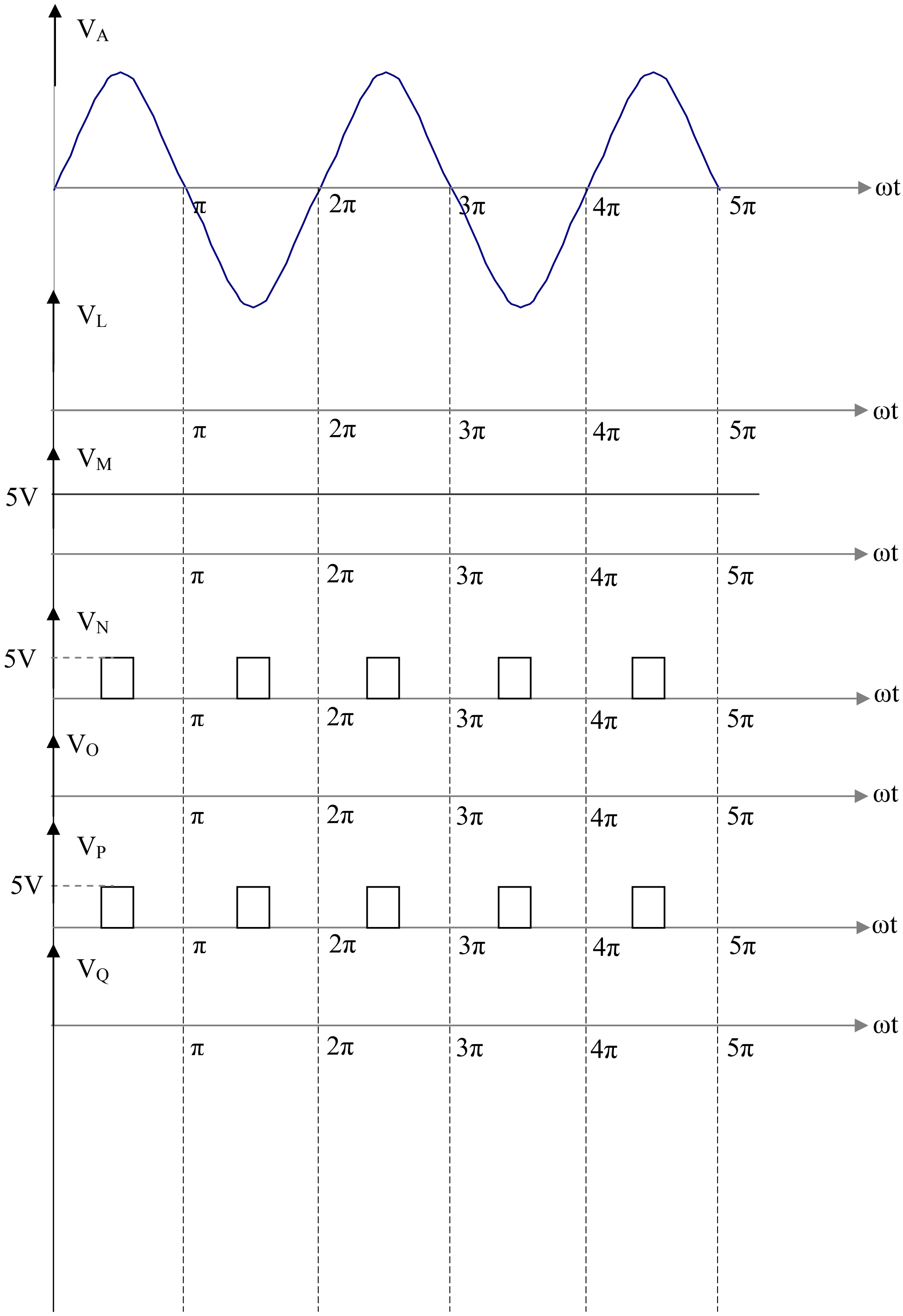


Fig.(3) The whole system waveforms

Governor circuit design:

This governor is designed for prime movers driving low voltage alternators. There is no complexity to extend this governor to operate with systems of higher ratings. The only modification is simply accomplished by choosing a new suitable DC driving motor and a new associated mechanical assembly. Here the design procedure is started at power circuit where the alternator output voltage is the unique power source to all governor circuits and offers the first exciting signal to governor operation.

1- Power circuit:

A step down voltage transformer of the following ratings is connected to the phase voltage of a 3-phase low voltage alternator:

Turn ratio = N1/N2=20

Primary voltage = 220 Volts r.m.s.

Power rating = 100 Watts

Operating frequency = 50 Hz

Two full wave rectifiers are used to generate two unstabilized DC voltages V1 (positive voltage) and V2 (negative voltage). The +12V, -12V, and +5V stabilizer offer the main DC voltage needed in this governor. Fig.(4) shows the complete power circuit. Note that the waveform at point A shown in fig.(3) is a sinusoidal waveform and is used as the main exciting signal to the governor after a processing procedure achieved later.

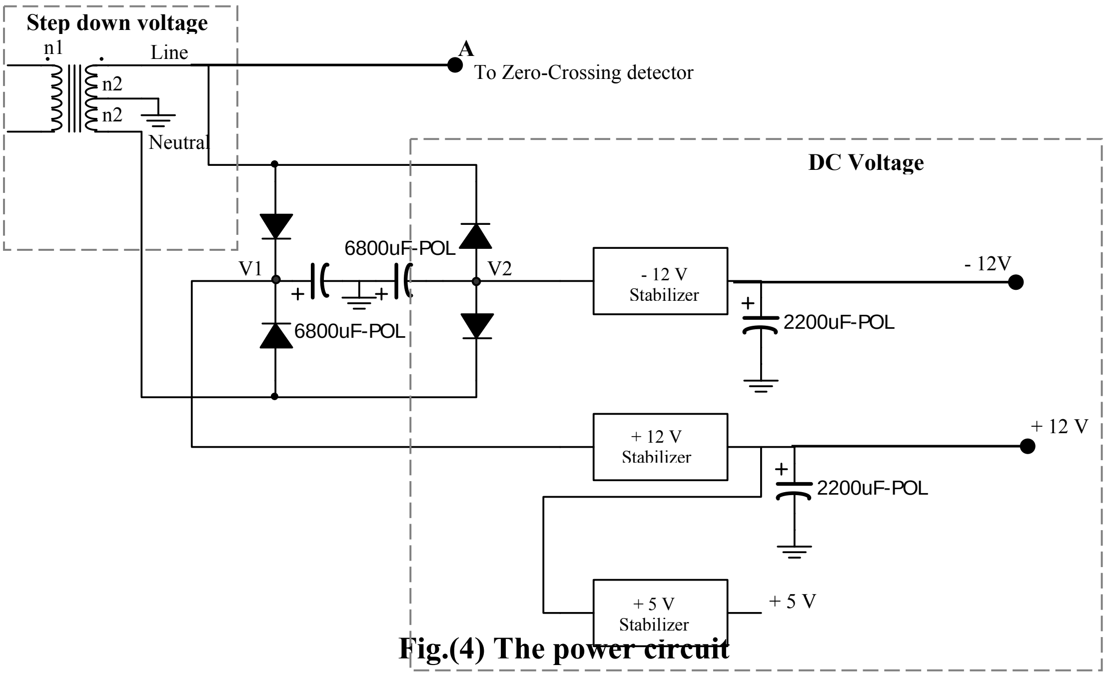


Fig.(4) The power circuit

2- The waveform generation circuit:

Fig.(5) shows the waveforms generation circuit. The first stage of this circuit is the zero crossing detector which generates a rectangular waveform of an amplitude of 5.1V and a frequency of (f) which is exactly the frequency of the phase voltage of the alternator. This waveform (fig.(3), point B) is processed in this circuit to generate two saw tooth waveforms of a frequency of (2f). The waveform at point D is a negative saw tooth of amplitude of -5V, while waveform at point E is a positive saw tooth of an amplitude of 5V. The rectangular waveform at point B is fed to the computation circuit.

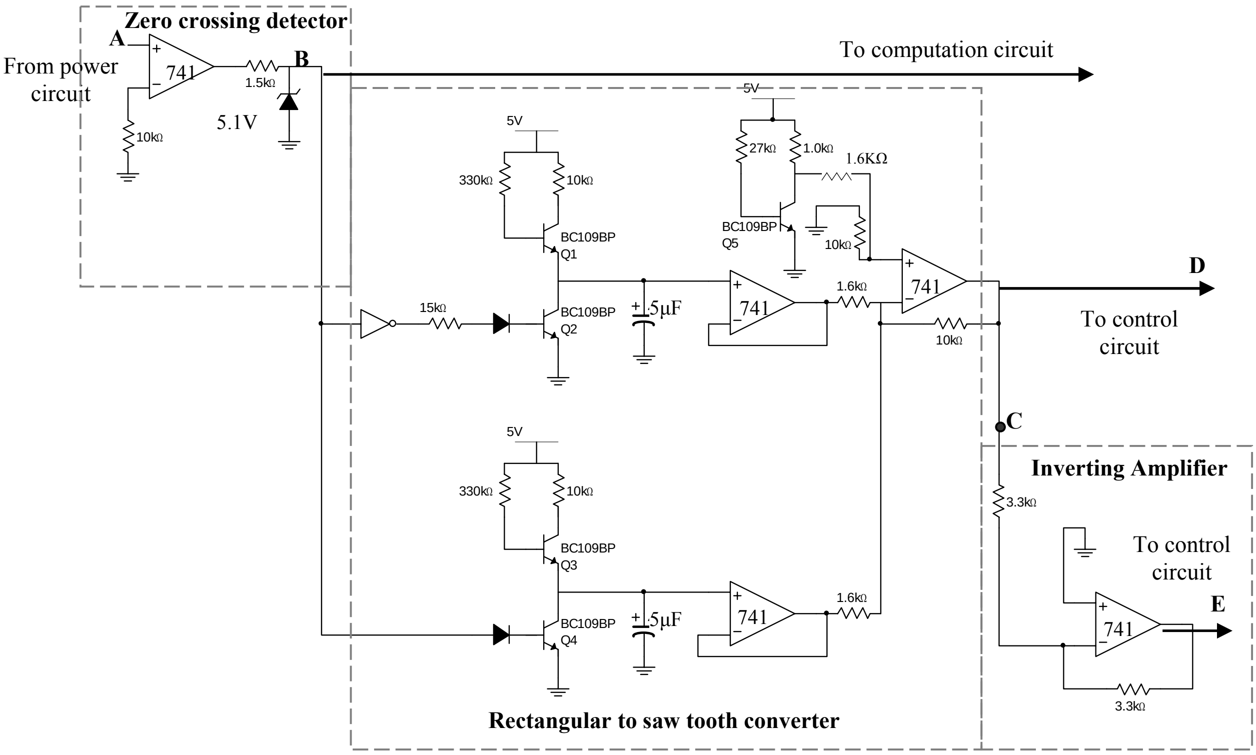


Fig.(5) The waveforms generation circuit

3- The computation circuit:

Fig.(6) shows the computation circuit which is an analogue computation circuit. The output of the differentiator circuit at point B is a negative pulse of an amplitude of -5.1V and of a frequency of (f), the period of this waveform is T=1/f . This circuit is designed to permit a variation of (f) to be within ±10% of the nominal frequency f_o=50Hz. T=20ms when f=f_o, T=18.18ms when f=1.1f_o, and T=22.22ms when f=0.9f_o=45Hz. V_H represents the DC value of V_G and it is of course the output of the DC filter which is designed in such away that the ripple factor of V_H is less than one percent. Here V_H is considered to be a pure DC voltage and is given by:

$$V_H = 1/T \int_{T/2}^{T/2+0.018} V_G \, dt = 0.09f$$

$4.05V \le V_H \le 4.95V$ for $45Hz \le f \le 55Hz$, V_H is always positive.

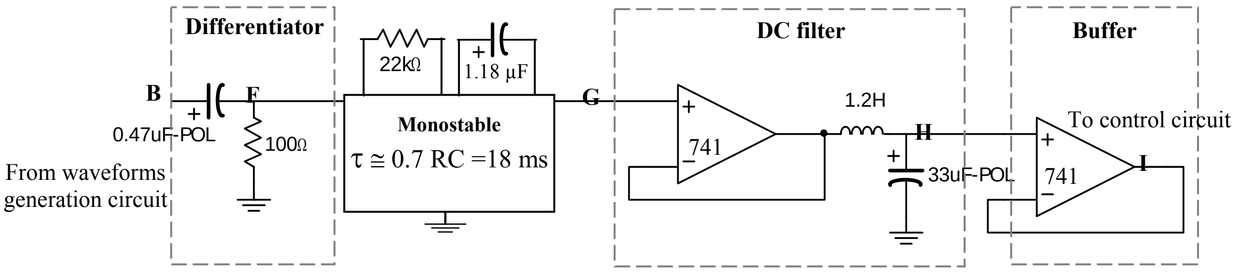


Fig.(6) The computation circuit

4- The controlling circuit:

Fig. (7) shows the controlling circuit. The output of the difference amplifier is $V_J = 10(V_I-4.5)$. The response decision amplifier plays a main role in accelerating and de accelerating the electric driver which is governing the hollow of prime mover fuel valve. The variable resistor in the response decision amplifier must be adjusted carefully in order to avoid saturation of the operational amplifiers. Comparators (1), (2), and (3) are designed such that when $f > f_o$, AND gate(1) is operative and AND gate(2) is out of order. The process is completely reversed when $f < f_o$.

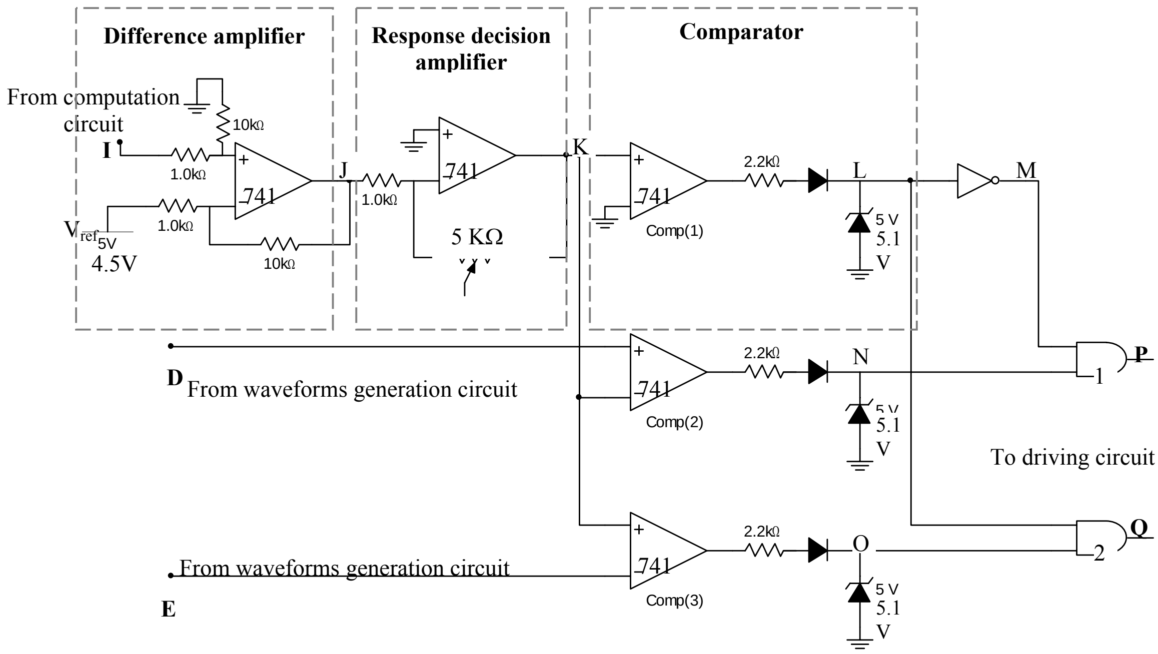


Fig.(7) The controlling circuit

5- The DC motor driving circuit:

Fig. (8) shows the driving circuit of the DC motor. When any of the two AND gate in Fig.(7) is operative, the amplitude of the rectangular waveform at its output (namely at point P or Q) is 5V. The average value of this waveform is depending mainly upon the DC level at point K. If the voltage level at point K is 5Volt, then the rectangular waveform will seem to be a continuous DC voltage of a level of 5Volt, while the zero voltage level at point K means a zero average value at point P or Q. Hence the DC level at point K offers a variation of the average value of the rectangular waveform at point P or Q within the range from zero Volt to 5 Volt. It is clear that the DC level at point K is depending upon the frequency deviation from f_o and the adjustment of the variable resistor of the frequency decision amplifier shown in fig.(7). When $f > f_o$, the input at P is activated and hence the composite transistors Q1 and Q4 are forward biased leading the DC motor to rotate in the direction so as to decrease the fuel valve hollow. When $f < f_o$, the input at point Q is activated leading the DC motor to rotate in the opposite direction so as to increase the fuel valve hollow. Note that the system circuits are designed in such a manner that when P is effective Q will be ineffective and vice versa. The circuit components of fig.(8) are chosen such that when the average value of the rectangular waveform at point P or Q is 5 Volt, then Q1 and Q4 or Q2 and Q3 are completely driven into saturation condition. Note that the DC motor is coupled through a mechanical assembly to the fuel valve.

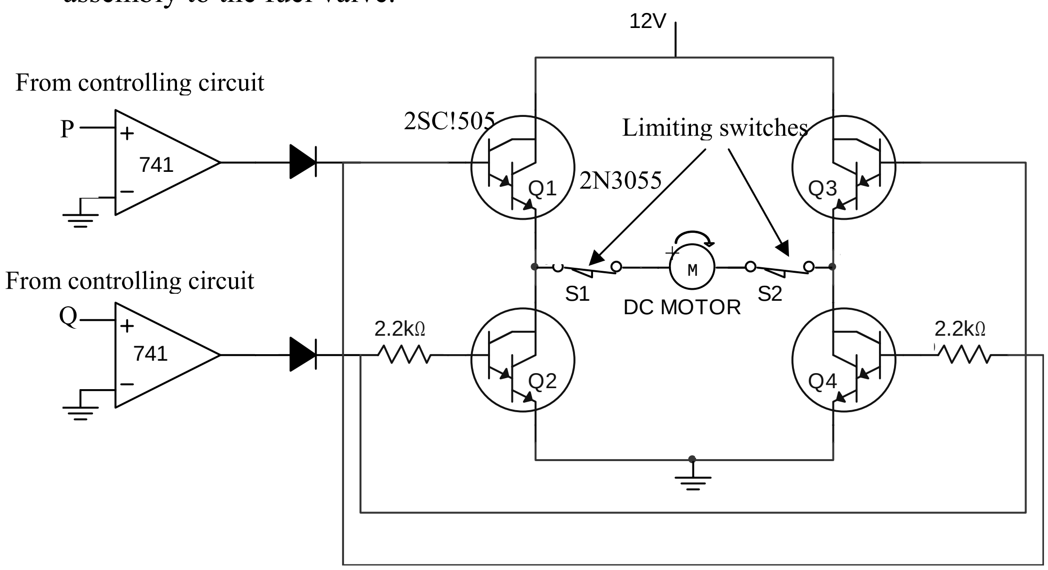


Fig.(8) The DC Motor driving circuit

6- The DC motor and the mechanical assembly:

A 12V DC motor is coupled to a gear box which has a speed advantage of 25:1. This means that when the speed at the Dc motor side of the gear box is 25 revolutions per second, then the speed at fuel valve side of the gear box will be 1 revolution per second. This reduction in speed offers a simplicity and availability of an angular movement of the fuel valve within the range from 0^o to 90^o. The 0^o angle means that the fuel valve gate is fully open, while 90^o angle means that the gate is fully closed. The angular movement of the fuel gate is governed smoothly within a range from 0^o to 90^o. The assembly is provided with two limiting switches connected electrically in series with the Dc motor as shown in fig.(8) and located at the positions of the zero angle and 90^o angle to avoid mechanical and electrical misleading. Fig.(9) shows the DC motor and the mechanical assembly.

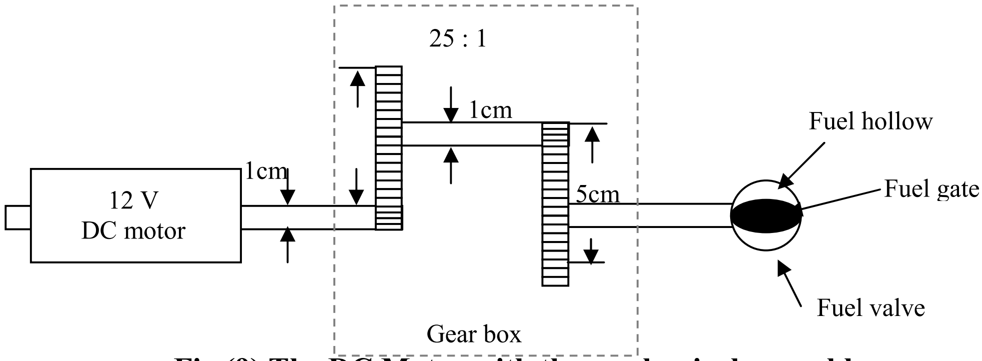


Fig.(9) The DC Motor with the mechanical assembly

Experimental results:

The implemented system gave the results shown in table (1) for a value of 1111.111 ohm of response decision resistor.

Table (1)

F (Hz)	V_H (Volts)	V_K (Volts)	V_P Pulse width(ms)	V_Q Pulse width(ms)	Normalized gear box(r.p.m.)	Direction of motor motion
45	4.05	5	0	11.11	1	Clock wise
46	4.14	4	0	10.87	0.8	Clock wise
47	4.23	3	0	10.64	0.6	Clock wise
48	4.32	2	0	10.42	0.2	Clock wise
49	4.41	1	0	10.20	0.2	Clock wise
50	4.50	0	0	0	0	--------------
51	4.59	-1	9.80	0	-0.2	Anti clock wise
52	4.68	-2	9.62	0	-0.4	Anti clock wise
53	4.77	-3	9.43	0	-0.6	Anti clock wise
54	4.86	-4	9.26	0	-0.8	Anti clock wise
55	4.95	-5	9.1	0	-1	Anti clock wise

It is clear that the gearbox r.p.m. is controlled within a range of (0--- ±100%) of its nominal value. For a value of 5kΩ of the control decision resistor, the frequency variation covered is ±2% of the nominal frequency, and the associated gearbox r.p.m. will be within a range of ±100% of its rated value. Hence the response of the implemented system is well controlled within the desired range and can be made faster as soon as desirable. This property make our system superior to the all types of governors mentioned above.

Conclusion

The implemented system is suitable for alternators operating in low voltage ranges up to 400V. It is very easy to extend the employment of this system to alternators of higher voltage ratings. The required changes are limited in the step down transformer in the power circuit which must be replaced by a potential transformer suitable for the new higher voltage and driving circuit associated with the electric driver and its mechanical assembly must be treated to be suitable for a larger prime mover.

This system is provided with a circuit which offers the possibility of continuous control of the governor response. Hence this facility represents a favorite option of applicable value of turbine speed governor regulation [Gamal et al 2004]. The possibility of response control serves the compatibility of this governor to a wide variety of prime movers.

References

Alghuwainem S.M. (1997) Steady-state analysis of a self –excited induction generator self-regulated by a shunt saturable reactor. IEEE International Electrical Machines and Drives Conference Record (IEMDC"97), MBI- 10.3, Milwaukee, USA.

Henderson D.S. (1993) Recent development of an electronic load governor for micro hydroelectric generation. Prac. of the Renewable Energy Conf., 385: 84-88.

Gamal A.B., El-Sadek M.Z., and Mubarak Y.A.(2004) Applicable values of turbines speed governor. Universities Power Engineering Conf., 2: 777- 781.

Marra E.G. and Pomilio J.A. (2000) Induction generator based system providing regulated voltage with constant frequency. IEEE Transactions on Industrial Electronics, 47: 908-914.

Schulte Robert P.(2000) Generation control for deregulated electric power systems. Power Engineering Society Summer Meeting, 2: 707-711.