Digital Excitation System for Synchronous Generator

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Abstract**--** Automatic voltage controllers for synchronous generators have traditionally utilized analog electronics. Modern voltage control systems are beginning to utilize the power, flexibility, and cost advantages of Digital Signal Processor for control. Digital excitation systems is a DSP based controlled devices. Digital excitation systems play a significant role in providing fast and accurate voltage control to the power system. In order to maintain system stability in interconnected system network it is necessary to have fast acting excitation system for large synchronous machines which means the field current must be adjusted extremely fast to the changing operational conditions. This paper deals with the design and simulation of a Digital excitation system for Synchronous generator excitation systems to improve the steady-state and transient stabilities. The performance of the proposed system is examined for voltage control application of synchronous Generator through simulation studies using the Psim software package.

Index Terms**—** *Digital excitation System, Automatic Voltage Regulator, Over excitation Limiter, under excitation Limiter, Stator current Limiter.*

I. INTRODUCTION

Excitation system of synchronous generator is the main equipment of operation and control of generators and power system [1]. The basic function of Digital excitation system is to provide direct current to the synchronous machine field winding. Also, the excitation system performs control and protective functions essential to the satisfactory performance of the power system by controlling the field voltage and thereby the field current [2]. The main control function of the excitation system is to regulate the generator terminal voltage which is accomplished by adjusting the field voltage with respect to the variation of the terminal voltage [3]. The basic requirement of the excitation system is to supply and automatically adjust the field current of the synchronous generator to maintain the terminal voltage as the output varies within the continuous capability of the generator [4].The terminal voltage can be affected by various disturbance so special regulating equipment is required to keep the voltage constant, even when affected by these disturbing factors. Also to maintain system stability in interconnected system network [5]. In addition the excitation system must be able to respond to transient disturbances with field forcing consistent with the generator instantaneous and short term capability. The generator capabilities in this regard are the limited by the several factor. To ensure the best utilization of the excitation system it should be capable of meeting the system needs by taking full advantage of the generator's short term capabilities without exceeding their limits [6]. From the power system viewpoint the excitation system should contribute to effective control of voltage and enhancement of system stability. It so as to enhance transient stability, and of modulating the generator field so as to enhance small signal stability[7]. Synchronous generator stability is graphically represented by P-Q diagram as shown in Fig 1. The operating point of generator must be inside the area determined by: under excitation limit, theoretically stability limit, over excitation limit. The control of excitation current for maintaining constant voltage at generator output terminals started with control through a field rheostat, the supply being obtained from DC Exciter. The modern trend in interconnected operation of power systems for the purpose of reliability and in increasing unit size of generators for the purposes of economy has been mainly, responsible for the evolution of new excitation schemes [4].

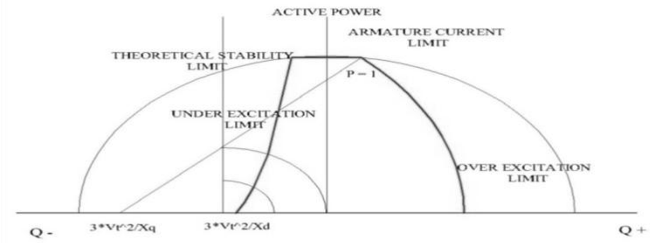

Fig. 1. Capability curve of synchronous generator

II. DIGITAL EXCITATION SYSTEM

In order to maintain system stability in interconnected system network it is necessary to have fast acting excitation system for large synchronous machines which means the field current must be adjusted extremely fast to the changing operational conditions. Besides maintaining the field current and steady state stability the excitation system is required to extend the stability limits. The Digital excitation system is DSP based control devices. In this system, the AC power is tapped off from the generator terminal stepped down and rectified and then fed to the generator field thereby controlling the generator voltage output. A high control speed is achieved by using an internal free control and power electronic system. Any deviation in the generator terminal voltage is sensed by

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an error detector and causes the voltage regulator to advance or retard the firing angle of the Thyristor thereby controlling the field excitation of the generator. This excitation system not only regulate terminal voltage but also employ various auxiliary control, limiting and protection functions. Limiting function generally have no role under normal operating condition. It is only when the synchronous machine is pushed beyond its operating capability that these limiters are brought in to play[9]. In addition the Digital excitation performs control and protective function essential to the satisfactory performance of the power system by controlling the field voltage and field current. The control function include the control of voltage, current and reactive power flow and the enhancement of the system stability. The protective function ensure that the capability limits of the synchronous machine, excitation system and the other equipment are not exceeded [7].

III. DIGITAL VOLTAGE REGULATOR

Regulator is the heart of the system. This regulates the generator voltage by controlling the firing angle of thyristor. Digital voltage regulator is designed for synchronous generator utilizing anti windup PI controller, to keep the terminal voltage of the generator to the rated value [3]. In DVR a reference Voltage ‘ Vref” is compare with a sensed terminal voltage Vt. If it determines that the generator voltage is incorrect, it produces an error signal, this error signal passes to the firing circuit. There, it overrides the control signal and causes the firing angle of thyristor rectifier to restore generator voltage to a desired level. [5].

IV. LIMITER CONTROLLER

When a generator is running in parallel with the power network, it is essential to maintain it in synchronism without exceeding the rating of the machine and also without the protection system tripping. Only automatic Regulator cannot ensure this. It is necessary to influence the voltage regulator by suitable means to limit the over excitation, under excitation and stator current limiter. This not only improves the security of the parallel operation but makes operation of the system easier. However limiters do not replace the protection system but only prevent the protection system from tripping unnecessarily under extreme transient conditions. The static excitation system is equipped with three limiters which act in conjunction with the AVR. These limiters are as under;

A. Over excitation limiter
B. Under excitation limiter
C. Stator current limiter

The excitation limiter tested as a summing point type device acting upon the set-pint of the automatic voltage regulator to provide restrictive control of the machine.

A. Over excitation limiter

The maximum excitation limiter senses the field current of the generator and similarly acts upon the set-point of the voltage regulator to restrict control of the machine where operation is undesirable. The capability of the generator in the overexcited region is limited by the capability of cooling the field winding and the overall MVA output (stator current) of the machine. The overexcited region of the machine is referred to as lagging power factor, where VAR are being supplied from the machine.[7] Over excitation Limiter or Maximum Excitation Limiters senses the field current output of static exciter and limits the field current to prevent field overheating [6]. Two OEL current levels are defined for off line operation. They are high and low as shown in the Fig. 2. The generator can operate continuously at the low OEL current level and for a programmed time at the high OEL current level. Over excitation limiter avoids thermal overloading of the rotor winding and is provided to protect the generator rotor against excessively long duration over loads. [8].

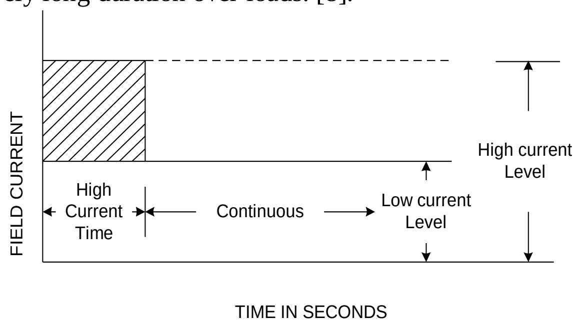


Fig 2 Off Line OEL Reference

The purpose of over excitation limiter is to protect the generator from overheating due to the prolonged field current. The generator field winding is designed to operate continuously at a value corresponding to rated load condition. The over excitation limiting function typically detects the high field current condition and after a time delay, acts through the regulator to ramp down the excitation to a present value.(typically 100 % to 110 % of rated field current). If this is unsuccessful, it trips the breaker and a unit trip[8]. Two types of time delay are used: (a) fixed time and (b) inverse time. The fixed time limiter operate when the field current exceeds the pickup value for a fixed set time, irrespective of the degree of over excitation. The inverse time limiter operate with the time delay matching the field thermal capability. The OEL controller is normally implemented as either “Take over” or a “summing” type controller. The summing type controller is consider here. The OEL make up the inner loop of the voltage regulator and use a PI controller [9]. The actual exciter field current in Amperes is used for the OEL models. and the OEL output is added to the summing point of the voltage regulator. When it is above the limit, the OEL limiter output becomes less than the AVR output and the OEL takes over to control at a proper excitation level. When the OEL is active, the AVR loop stops integration and compares its output with the OEL output to get out of the OEL loop.

B. UNDER EXCITATION LIMITERS

Under excitation limiters are included in most modern voltage regulators applied on large synchronous generators. An under excitation limiter (UEL) acts to boost excitation whenever it senses a condition in which generator excitation level is determined to be too low. The UEL typically senses either a combination of voltage and current of the synchronous machine or a combination of real and reactive power. The limits are determined by machine operating point crossing a reference level or characteristic. When the reference level or characteristic is crossed, the UEL output signal acts to become a part of the control of the excitation system. The UEL output is applied in the voltage regulator either to a summing junction to add the normal voltage control or to a high value (HV) gate to override the normal action of the voltage regulator. Depending upon the implementation of the UEL function to control excitation, the action of the UEL could take the voltage regulator out of service and/or cause interactions which may not normally occur during normal operation when the UEL characteristic is not reached. Two UEL models have been developed:1) Circular characteristic 2) multiple-segment straight-line characteristic. In this paper multiple-segment straight-line characteristic of UEL model is used.. For this model, the UEL limit has multi-segment Characteristic when plotted in terms of machine reactive power output (Qt) vs. real power output (Pt). The UEL limit can be unaffected by terminal voltage Vt. In the UEL real power Pt is sent to the UEL Look-up Table to determine the corresponding normalized value of the reactive power Qref at the UEL limit characteristic, which is compared with the machine reactive power Qt. Fig. 3. shows a UEL limit characteristic for a UEL in which the limit is comprised of multiple straight-line segments, showing the maximum of six segments. The UEL characteristic can be comprised of any number of straight-line segments from 1 to 6. The data requirements to the P and Q values used to specify the UEL limit are those values which would be applicable with VT = 1.0 pu. For any value of Pt, the corresponding value of Qref can readily be determined from look up table[10]. This Qref is compare with the Qact and produce error signal. According to the error signal UEL produce the output signal Vuel. This Vuel is Added with the Summing junction point of AVR.

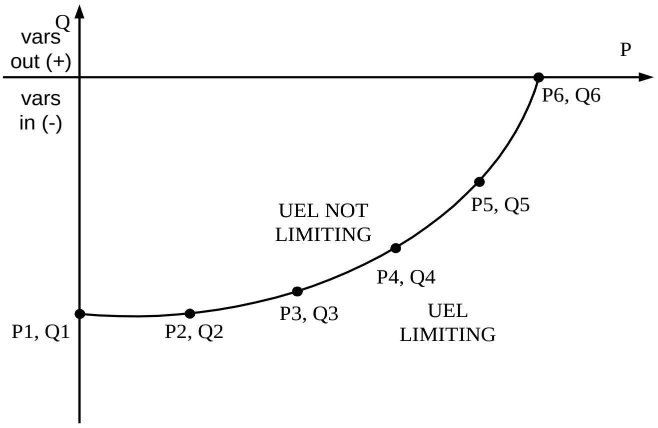


Fig.3 UEL Multi-Segment Normalized Limiting Characteristic

C. STATOR CURRENT LIMITER

Stator current limiter avoids thermal over loading of the stator windings. Stator current limiter is provided to protect the generator against long duration of large stator currents.

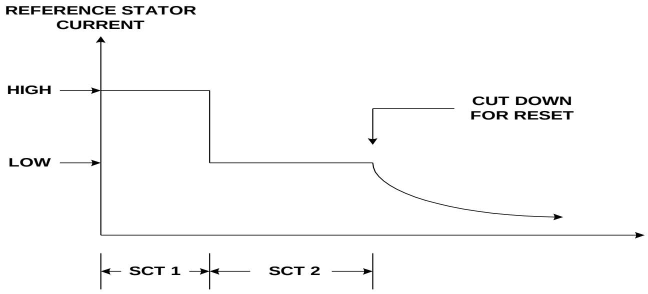


Fig 4 Stator Current Limiter Reference

The SCL current reference is generated based on a two-step waveform with a high current level and a low current level as shown in Fig. 4. For excessive inductive current it acts over the AVR after a certain time lag and decreases the excitation current to limit the inductive current to the limit value. But for excessive capacitive current it acts on the AVR without time delay to increase the Excitation and thereby reduce the capacitive loading. This is necessary as there is a risk for the machine failing out of step during under excited mode of operation.

V. SIMULATION AND RESULT

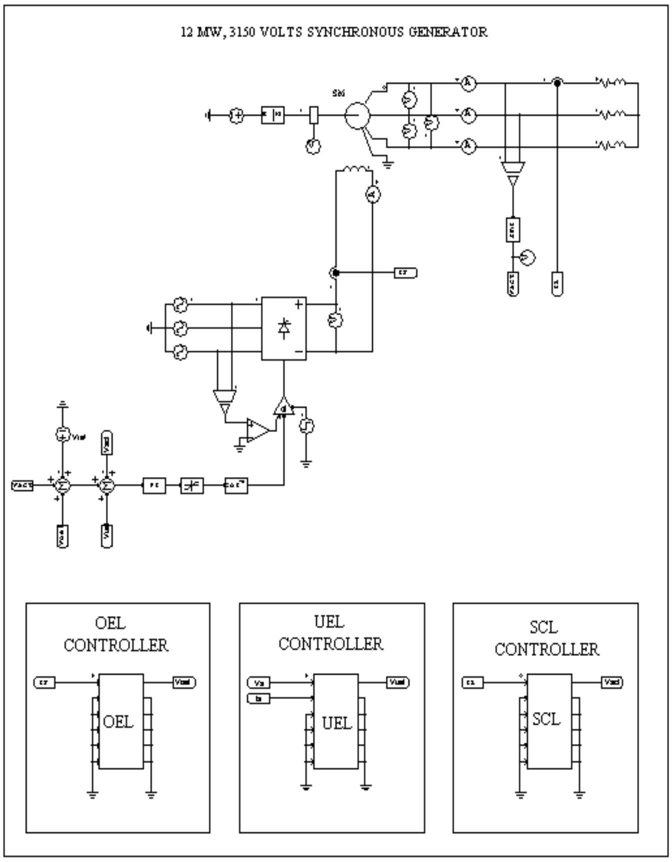
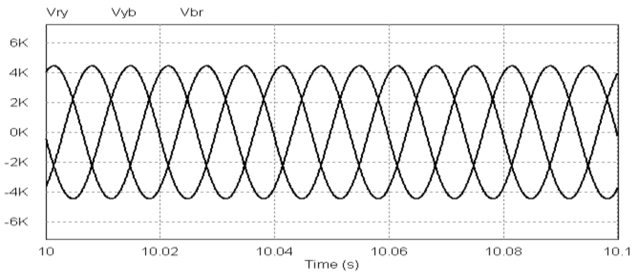


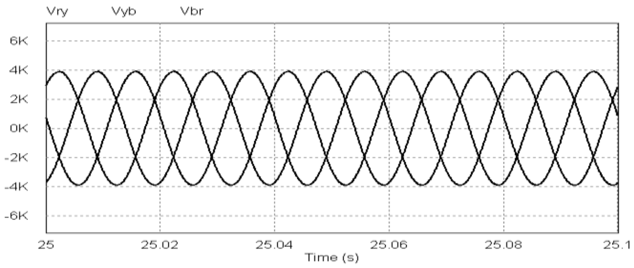
Fig.5 Simulation circuit diagram of Digital excitation system

Fig shows the simulation circuit diagram of Digital excitation system. Digital excitation system consist of AVR with limiter controller like Over excitation limiter, Under excitation limiter and stator current limiter. The main objective of AVR is to maintain constant output voltage at different loading condition. In OEL and SCL actual field current and stator current is compare with the reference current which is generated by the OEL and SCL controller. The output of the limiter is Voel and Vscl is zero when the actual current is within limit but whenever current is exceed for prolonged period the limiter output Voel and Vscl is negative and take the action to reduce excitation to a safe value. In the UEL under normal conditions when the UEL is not limiting, the Vuel signal is zero, since the reactive power Qt will be greater than the limit value Qref. When conditions are such that the UEL limit is exceeded, Vuel becomes positive. This will drive the UEL output in the positive direction, and if the gain is sufficient, the UEL output will take over control of the voltage regulator to boost excitation to move the operating point back toward the UEL limit.

A. *Simulation Result of OEL*

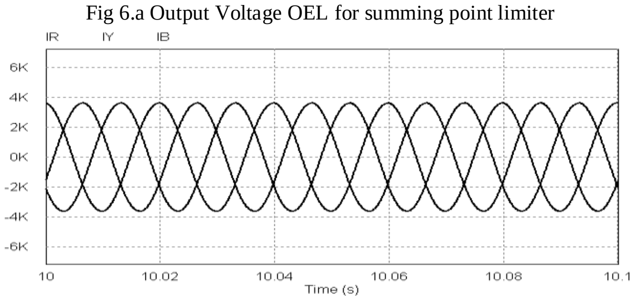


(Vry = 3146.68, Vyb =3150.04 and Vbr = 3150.68)

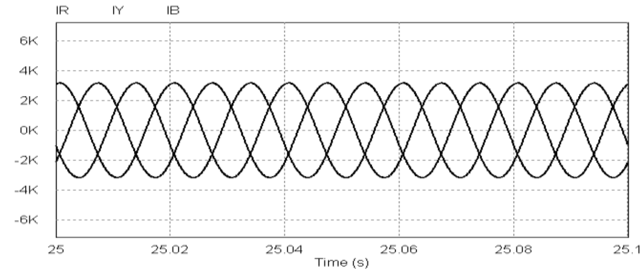


(Vry = 2754.84, Vyb =2752.68 and Vbr = 2756.34)

Fig 6.a Output Voltage OEL for summing point limiter

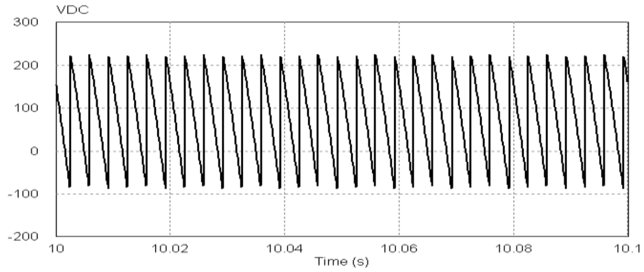


(IR = 2560.14, IY =2559.96 and IB = 2562.71)

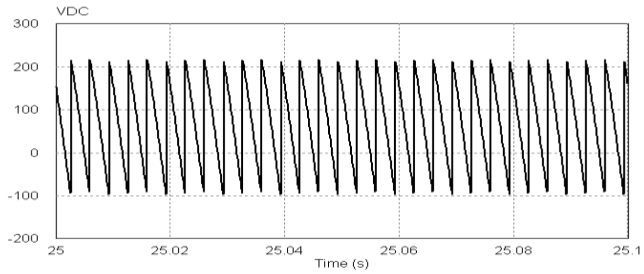


(IR = 2241.52, IY =2238.64 and IB = 2239.85)

Fig 6.b Output current of OEL for summing point limiter

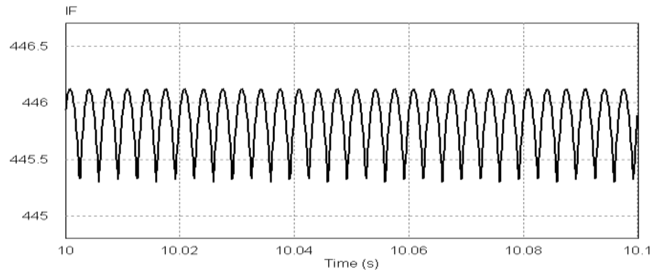


(Vdc = 75.82 volts)

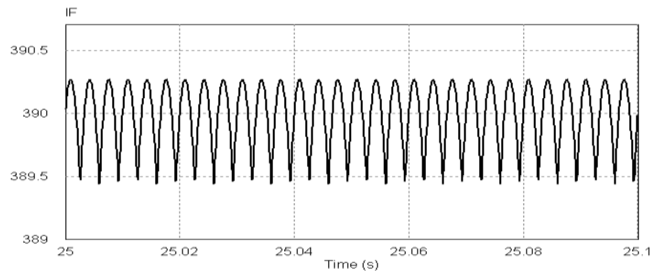


(Vdc = 66.34 volts)

Fig 6.c Field Voltage of OEL for summing point limiter



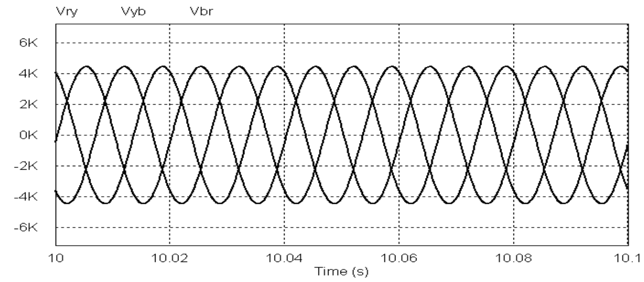
(If = 445.84 A)



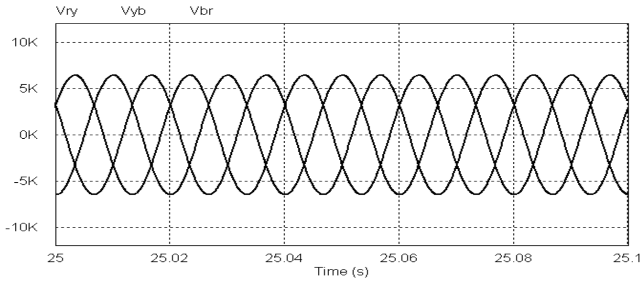
(If = 389.98 A)

Fig 6.d Field Current of OEL for summing point limiter

B. *Simulation Result of UEL*

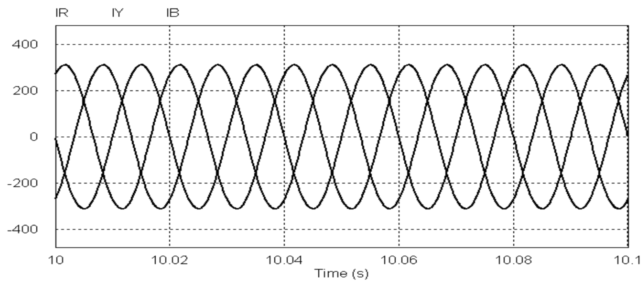


(Vry = 3150.65, Vyb =3148.50 and Vbr = 3151.27)

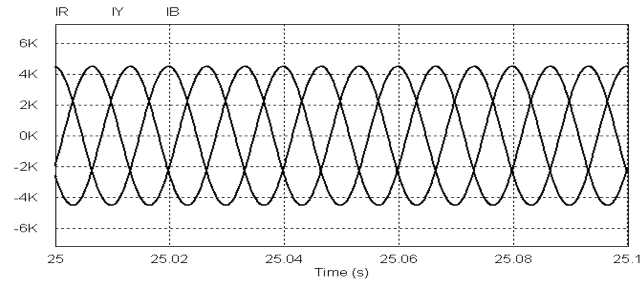


(Vry = 4566.44, Vyb =4566.27 and Vbr = 4567.15)

Fig 7.a Output Voltage of under excitation limiter

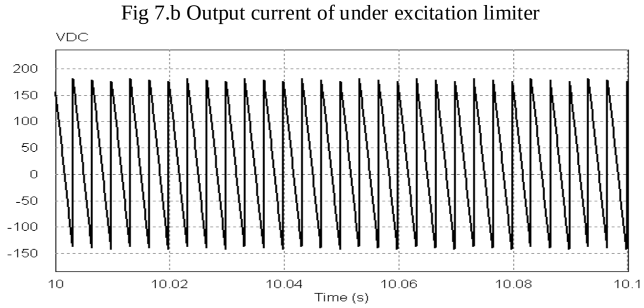


(IR = 219.93, IY =219.92 and IB = 219.74)

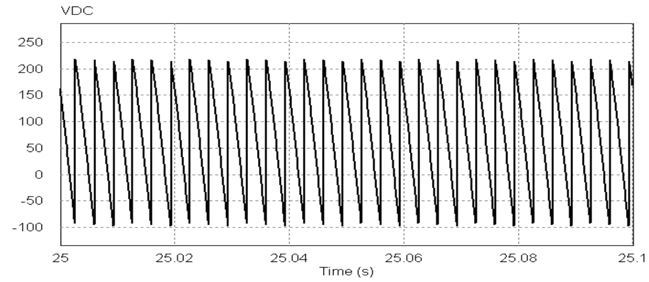


(IR = 3187.90, IY =3187.90 and IB = 3187.09)

Fig 7.b Output current of under excitation limiter

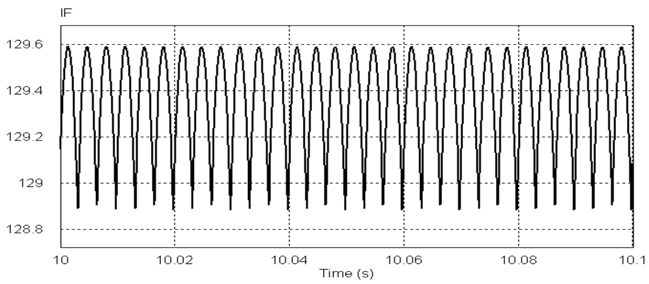


(Vdc = 21.80volts)

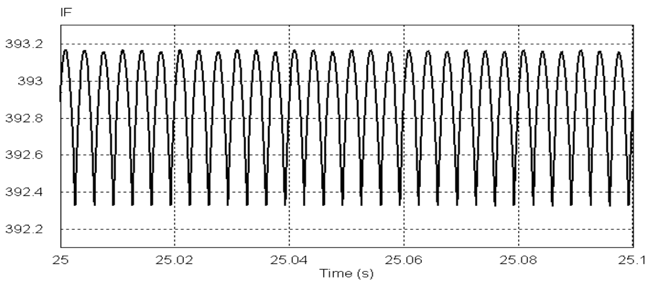


(Vdc = 66.88 volts)

Fig 7.c Field Voltage of under excitation limiter



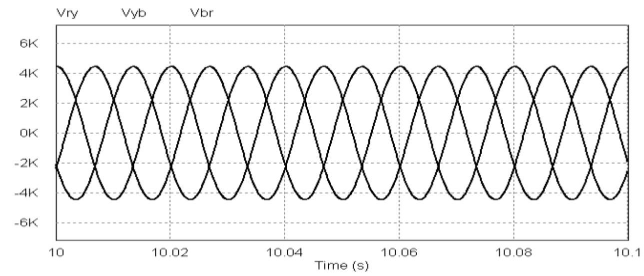
(If = 129.35 A)



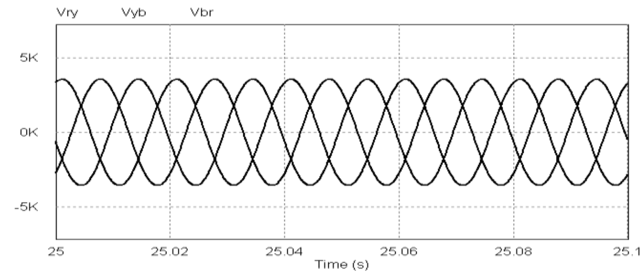
(If = 392.87 A)

Fig 7.d Field Current of under excitation limiter

C. *Simulation Result of SCL*

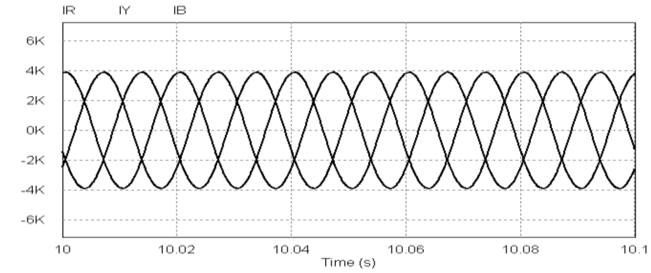


(Vry = 3148.53, Vyb =3149.03 and Vbr = 3151.33)

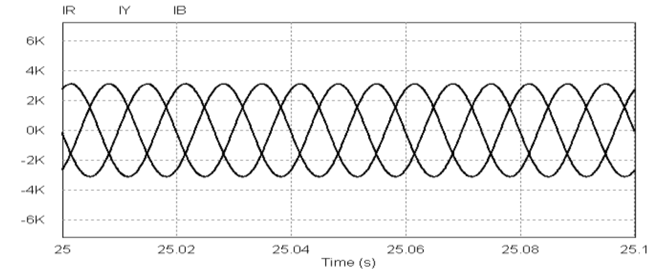


(Vry =2520.17, Vyb =2519.67 and Vbr = 2519.93)

Fig 8.a Output voltage of stator current limiter

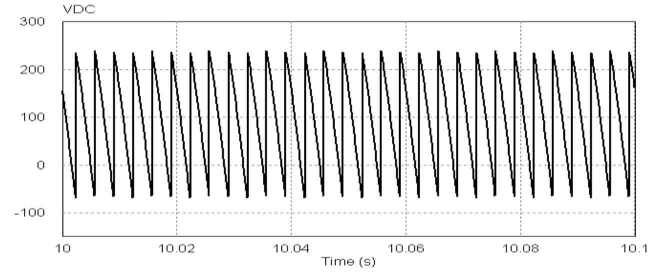


(IR = 2748.95, IY =2750.03 and IB = 2751.56)

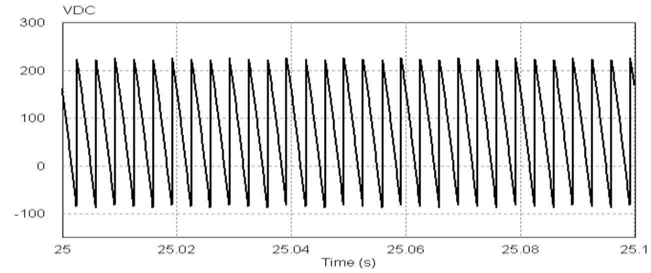


(IR = 2200.05, IY =2199.96 and IB = 2200.34)

Fig 8.b Output current of stator current limiter

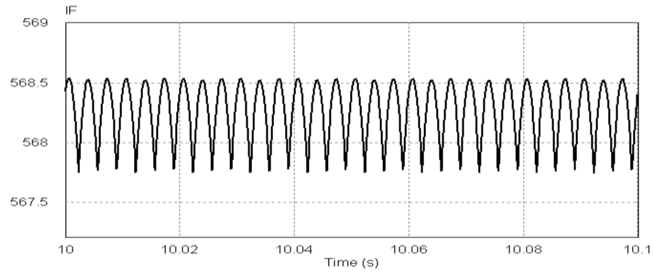


(Vdc = 93.69 volts)

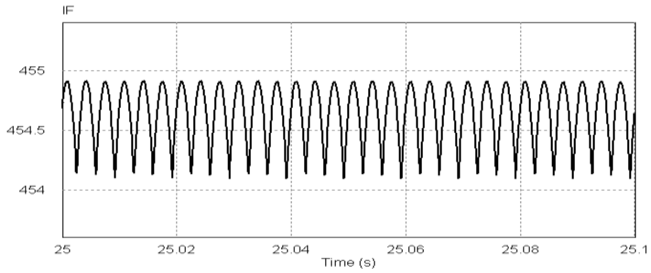


(Vdc = 76.67 volts)

Fig 8.c Field Voltage of stator current limiter



(If = 568.24 A)



(If = 370.67 A)

Fig 8.d Field Current of stator current limiter

VI. CONCLUSION

In this paper Digital excitation system using thyristor rectifier converter is simulated. In order to improve the generator stability under unbalanced conditions, this generator excitation system is proposed. This excitation system gives better stability than a conventional excitation system. The performance of the proposed excitation system has been verified through computer simulation. The over excitation, under excitation and stator current limiter allows operating for a period of time within the machine or equipment limits until corrective measures can be taken, even when failure. For these reasons, limiters used on generation provide both performance and economic benefits to the user, to insure reliable power generation.

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