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## Simulation of Generator Over-Flux Protection using MATLAB

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**ABSTRACT:** A three phase synchronous generator is a critical or vital component of power system used in captive and independent power plants in various capacities. To protect the generator against power system abnormalities or fault within itself, it requires quick isolation from the system for maintaining stability in the system. As generators are exposed to more harmful operating conditions than any other power system element, therefore sophisticated and innovative protection schemes are required. However selection of protection scheme requires throughout knowledge of protection philosophy of ac machine. As the pace of technological change has rapidly accelerated so, In today's scenarios electromechanical type of relays are absolute which were used for each individual protection function and instead of that a single multifunction digital/numerical relay with various features are used as a complete generator protection package. One of the major advantage of these relays are that these are working in a common protocol (IEC61850) irrespective of its make (SIEMENS, ABB, AREVA) and facilitate the logics blocks as per the requirement of end user. These relays are used to input analogue signals from neutral side CT's and Phase side CT's and VT's for various computations and algorithms and accepts user configurable inputs and outputs, substation control system interfaces, disturbance recording, etc.

In this project we are considering over-flux protection scheme of generator and simulate the function using Matlab Simulink. In this cases Turbine, generator and its excitation are considered as a dynamic sources. The pick-up of a protection function initiates opening of Generator CB, shut-off driving force to turbine ( $P_m$ ) and switched off field excitation ( $E$ ), which enables the generator terminal voltage drops to zero instantaneously and isolate machine from bus-bar. The protection function shows in subsequent pages with events in its respective work-sheet.

**KEYWORDS:** Gen Circuit breaker (52), Emergency stop valve(ESV), Intercept valve (IV), Unit lock-out relay group-1(86G-1), Unit lock-out relay group-2(86G-2), Generator Over-flux relay(24G), Automatic voltage regulator (AVR).

### I. INTRODUCTION

In a generating station, Turbine, Generator, Transformer and other high voltage switch gears are critical as well as expensive equipment's and hence it is advisable to employ a passive protective system so that it can be isolate the faulty equipment as quickly as possible and keep the healthy section in normal operation to ensure un-interruptible power supply to customer or to maintain grid stability. The basic electrical quantities which are deviated under abnormal fault conditions are voltage(V), current(I), phase angle( $\Phi$ ) and frequency(Hz), the protective relays senses/utilises one or more of these quantities to detect abnormal conditions in the system and isolate it. As a standard cost of protective system would be 6-7% of total electrical installation cost.

For achieving high performance and long functional life of generator it requires periodic maintenance and testing activities to be conducted at regular intervals for diagnosis and healthiness of machine. The generator is subjected to various internal and external faults during its operational life which deteriorates it's winding, insulation (F-class), core, field winding, retaining rings etc. Therefore a generator has to be protected not only from electrical faults (stator and rotor faults) and mechanical problems (e.g. related to turbine, boilers etc.), but it also has to be protected from adverse

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system interaction arising like generator going out of step with the rest of system, loss of field winding etc. Under certain conditions like severe internal faults machine has to be quickly isolated and in certain alarming conditions like loss of field, generator over voltage stage-1, generator under voltage stage-1 etc. it will issue an alarm signal to alert the operator. Hence different types of primary and back-up protections are employed for generators which are described further.

## II. METHODS AND SYSTEM MODEL

**a) Faults on generators:** Faults on generators are classified in different manners which are described as

### *Stator faults*

- i) Phase to phase fault on windings.
- ii) Phase to ground faults
- iii) Inter-turn faults that is shorting of same phase winding

Phase to phase faults and inter-turn faults are less common and these are developed into earth faults but inter-turn faults are difficult to be detected.

### *Rotor Faults* which includes

- i) Phase to ground fault in rotor winding
- ii) Shorting of turns of field windings
- iii) Loss of excitation protections
- iv) Protection against rotor over heating because of over excitation
- v) Rotor high temp alarm
- vi) Automatic field suppression and use of neutral circuit breaker
- vii) Alternate arrangement for field suppression

### *Abnormal operating conditions*

- i) Over/under voltage in stator winding
- ii) Over loading condition
- iii) Over/under frequency
- iv) Loss of field
- v) Negative sequence protection against unbalanced loads
- vi) Motoring or Loss of Prime-mover
- vii) Protection against vibration
- viii) Overheating of bearings
- ix) Sub-synchronous oscillation
- x) Loss of synchronism (Out of step)
- xi) External fault back-up protection

**b) Constructional block diagram for generator:**

In the Fig-A below shown the block diagram of generator, which is driven by prime-mover, it may be steam turbine, hydro turbine or diesel engine. Generator is supplying power to 3 phase load and output sinusoidal waveform of generator is shown in the block. Generator field is supplied with DC regulated source called AVR (Automatic voltage regulator panel) which tuned to machine capability limits. There are different configuration of AVR system basically it is either **Static** or **Brush-less excitation**. For static system it derives input power from generator terminals through excitation transformer of adequate rating and for brush-less system main exciter and PMG (Permanent magnet generator) are used. In present scenario brush-less system is more favoured owing to large maintenance at slip rings of generator rotor due to large magnitude of field current in static system. Small generators (up to 25 MW) are directly connected to distribution board with generation voltage of 6.9/11 KV but for large generators (up to 600 MW) we are using UNIT system having one GT (Generator transformer) and UAT (Unit auxiliary transformer) with High impedance earthing by using NGT (Neutral grounding transformer) and generation voltage selected as 16.5KV.

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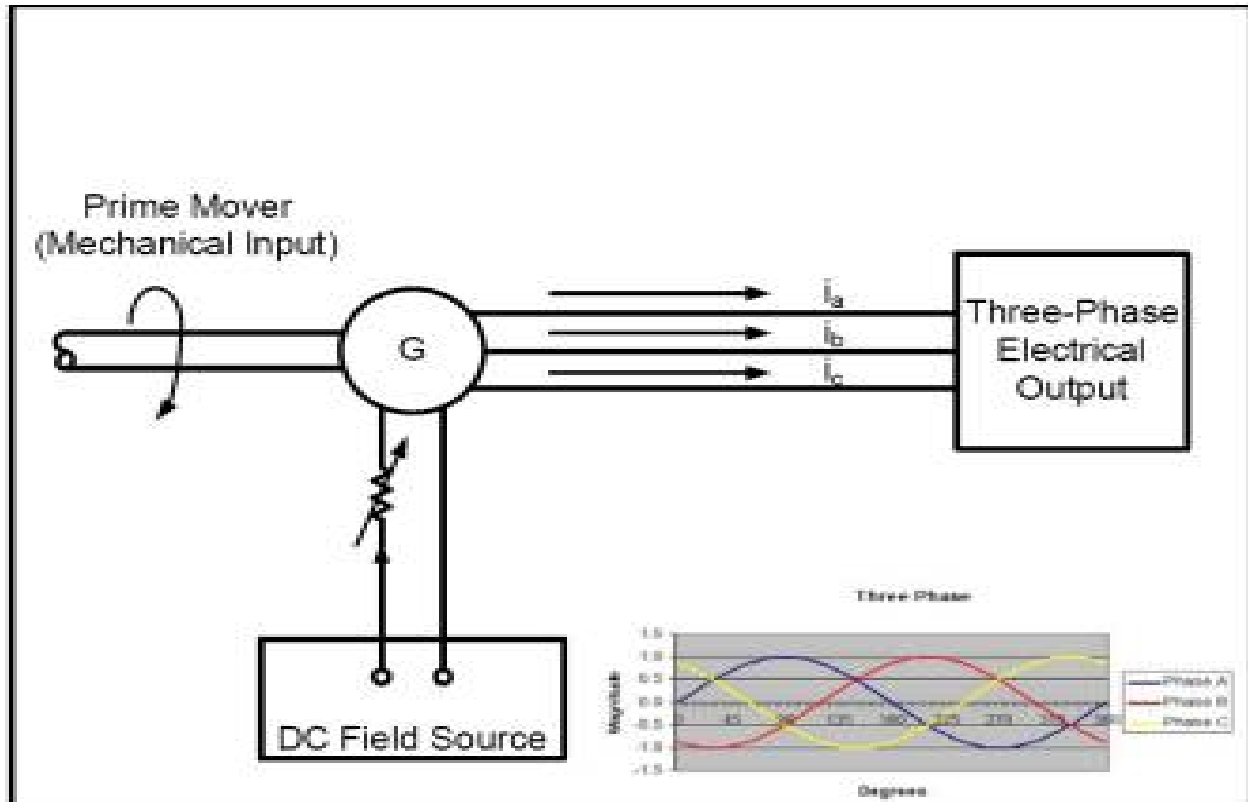


Fig A-Generator block Diagram

### c) Device nomenclature for generator protection

Each generator is protected with some of standard protection functions some of which are called as unit/primary protection and other are called as back-up/secondary protection schemes, generators above 25MW are equipped with all these protections as tabulated below. These device nomenclatures are as per IEEE norms and each device number has specific function name used for generator and transformer protection. These protection functions names are unique which are used for various electrical equipment and switchgears such as generators, motors, feeders, line protection, transformers, HV/LV distribution boards etc. In present scenario, most of the protections are incorporated in a single multifunction relay as detailed above. For the costly and higher rated equipment two similar protection relays are used as 100% back-up and redundancy.

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Sr No	Device Nomenclature	Function Description	Primary/Backup
1	87G	Generator Differential protection	Primary
2	59G1, 59G2	Generator Over voltage	Primary
3	59N1, 59N2	Neutral over voltage(95% and 100%) stator earth fault	Primary
4	64S	Stator earth fault relay	Primary
5	51VG	Voltage dependent over current	Primary
6	32G	Gen reverse power- Anti motoring protection	Primary
7	46G	Negative sequence relay	Primary
8	64F	Rotor earth fault protection	Primary
9	81O	Over frequency protection	Primary
10	24	Over Flux/Over excitation protection relay	Primary
11	87T	Transformer differential protection (When GT used)	Primary
12	87O	Overall differential protection (In a unit scheme)	Primary
13	50BF	Local breaker back-up protection	Primary
14	27/40G	Loss of field with under voltage	Primary
15	40G	Loss of field w/o under voltage	Secondary
16	27G	Stator under voltage protection	Secondary
17	81U	Under frequency protection	Secondary
18	78	Out of step or Pole slip Relay	Secondary
19	21G	Distance protection-back-up for system generator ph- fault	Secondary
20	47G	Unbalance protection	Secondary
21	49	Stator thermal over load protection	Secondary
22	60	Voltage balance relay- detection of PT fuse blown	Alarm
23	86	High speed master trip relay latch type (Manual reset)	Trip
24	25	Sync- check relay (SKE)	For Syn

### d). ANSI/IEEE standard for generator protection

The revised standards for generator protection are as given below.

Standards	Description
C37.101	IEEE guide for generator earth fault protection
C37.102	IEEE guide for generator protection
C37.106	IEEE guide for abnormal frequency protection for generating units

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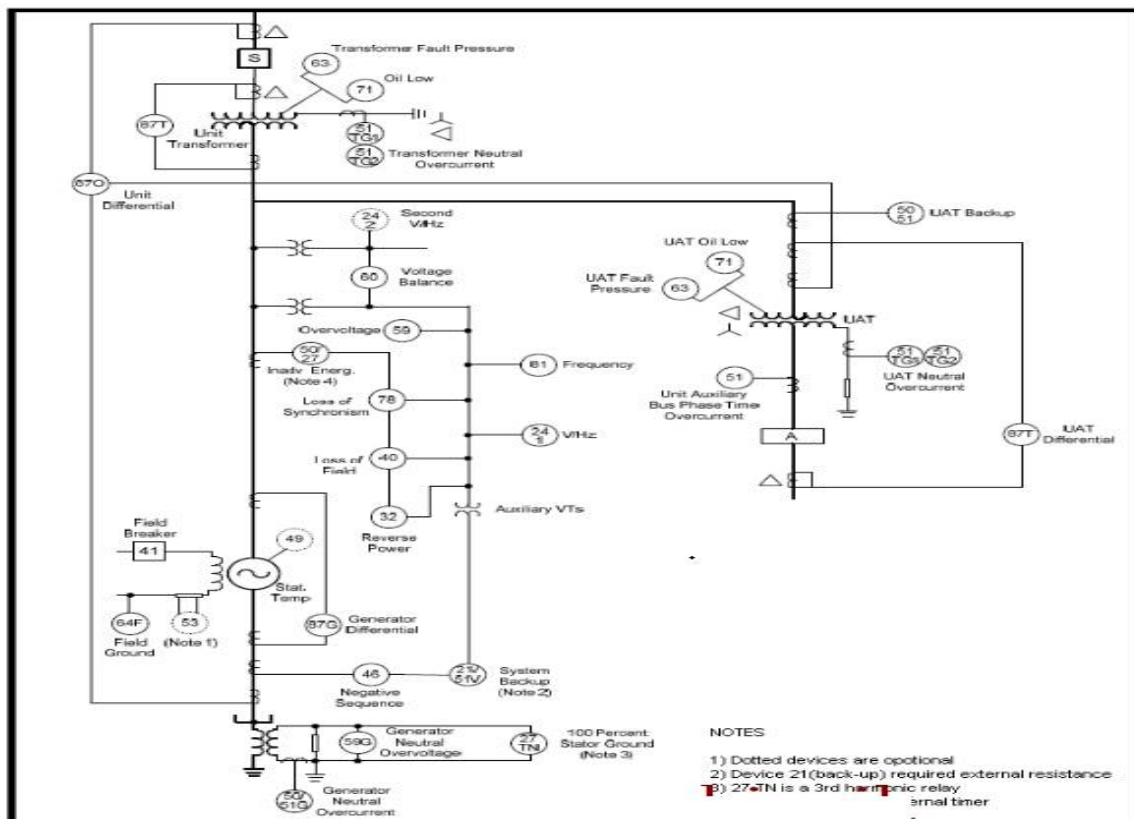
**Note-** These are created/maintained by IEEE, PSRC(Power system fault relaying and control committee) and IAS (Institute for advanced study) and updated for every 5 years.

### e) Protection scheme (model) for unit connected generator:

The fig-B below shows the typical protection model for a unit connected generator, there are three major and critical equipment for unit connected scheme ie

- i) Generator
- ii) Generator transformer (GT)
- iii) Unit auxiliary transformer(UAT)

Each equipment in this scheme has individual differential protection as well as with combined overall differential(87O) which acts as back-up for individual differential relay. Generator has high impedance grounding with 3<sup>rd</sup> harmonic stator earth fault protection with generator neutral over voltage relay. GT and UAT are additionally equipped with over current, earth fault protection with its gas operated mechanical protection such as Buchholz, OSR, PRV, WTI and OTI. Generator rotor is protected with 1<sup>st</sup> rotor E/F and 2<sup>nd</sup> rotor E/F protection in addition to field failure protection(40G). In unit protection scheme as a standard practice for vector group of GT and UAT are YNd11 and DYn1 respectively. Generator CT and VT are connected to current and voltage coil of individual protective function as shown in the figure.



*Fig-B- Unit protection scheme*

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## III. CONTRIBUTION AND SCOPE OF RESEARCH

### a) Description of Over-fluxing:

Per unit voltage divided by per unit frequency is called over fluxing which is a measurable quantity and proportional to flux developed in generator and transformer core. A moderate over-fluxing of 105-110% increases core losses because of hysteresis ( $W_h$ ) and eddy current losses ( $W_e$ ) occurs in core, resulting of increase in core temperature. Long time operation of machine may damage the core insulation both in case of generator and step-up transformer (GT). Severe over-fluxing can damage the inter-laminar insulation followed by localized core melting. The six main reasons for over-fluxing are

- i) Over speeding of turbine
- ii) Load rejection on machine due to tripping a block of load
- iii) AVR malfunctioning in machine operating condition
- iv) Over excitation during machine off load condition.
- v) When machine runs at higher terminal voltage than rated.
- vi) When machine runs at rated /less then rated voltage with lower frequency.

The core lamination can withstand relatively high over-fluxing without becoming excessively heated, but unlaminated metallic parts can experience severe heating in a short time. The recommended settings of over-fluxing for any machine is 115% for 10 sec gives Alarm and 125% for 30 sec issues trip signal.

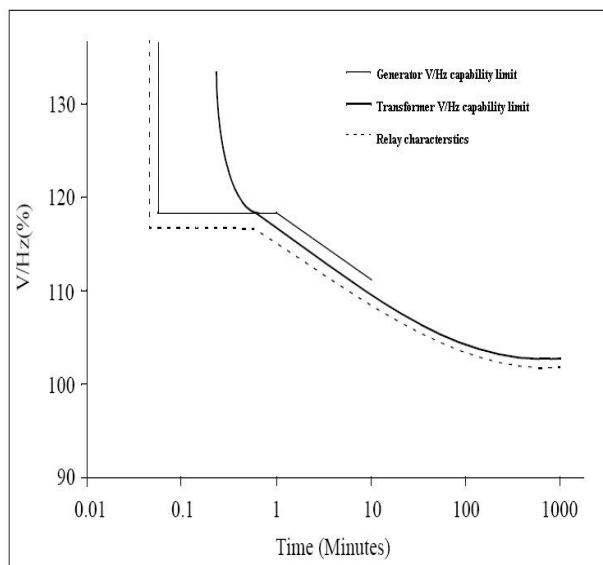


Fig C- V/Hz characteristics of Gen-transformer unit using both Inverse squared and definite Time characteristics.

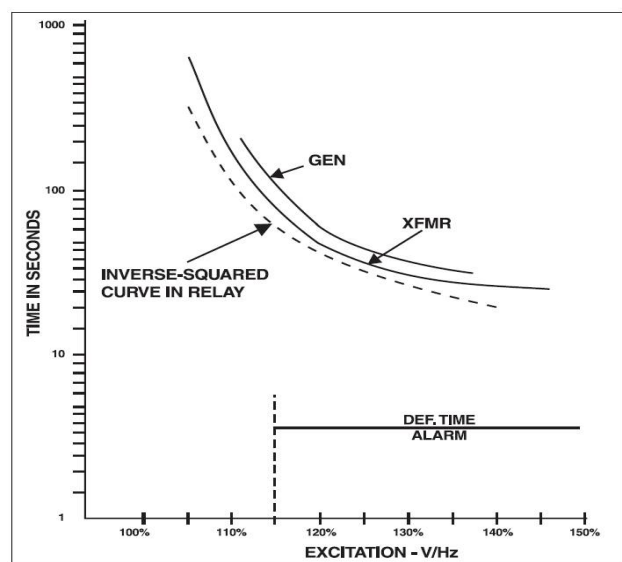


Fig D- Combined V/Hz characteristic of Gen-transformer

An example on the V/Hz capability curve for a generator and the unit transformer is shown in Fig-C. The combination of a definite time-delay stage and a suitable inverse time will match the combined characteristic quite well. Most international standards for power transformers specify a limit of maximum 5 % continuous amount of over excitation (over-fluxing) at rated load current and max, 10 % over-fluxing at no load. As long as the generator-transformer unit is connected to the network, the risk of over-excitation is relatively small. However, when the generator transformer unit is disconnected from the network, there is an obvious risk for over-excitation, mainly

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during generator start up and shut down. From cases reported in existing literature it can be concluded that over-fluxing occurs relatively often compared to the number of other electrical incidents. The risk of over-excitation is, obviously, largest during periods when the frequency is below rated value. Hence, over voltage relays cannot be used to protect the generator-transformer unit against over-fluxing. The proper way of doing this is to use a relay which measures the ratio between voltage and frequency (V/Hz relay). For a given flux level, the voltage output of a machine will be proportional to its frequency. Since maximum flux level is designed for normal frequency and voltage and when a machine is at reduced speed, voltage produced by it is proportionately reduced to maintain its Flux level. A volts/hertz relay (24) responds to excitation level as it affects thermal stress to the generator (and to any transformer connected with that generator). IEEE C50.13 specifies that a generator should continuously withstand 105% of rated excitation at full load.

With the unit operated in Island mode with reduced frequency, the machine subjected to over excitation if it do not have over excitation limiter. Over-excitation also occurs when machine limiter has out of service OR defective. If voltage balance scheme has not provided in protection scheme then failure of PT fuse (excitation core) may also results have over excitation of machine and cause of spurious tripping. The Over-flux relay prevents over-excitation if it is scenes PT voltage through voltage balance scheme. As per standard schematic 1<sup>st</sup> stage and 2<sup>nd</sup> stage over flux are linked up to changeover excitation system from Auto ref to Manual and for trip respectively. The fig-D shows Generator and transformer inverse squared V/Hz characteristic individually which is generally used for trip the machine and DT characteristic is used to give alarm and excitation change-over to Manual. The generator and transformer manufacturer should supply the specific capabilities of these units. Phase over voltage (59) and under voltage(27) acts as back-up for excitation system problem.

## b) Type of relay used:

Any micro-processor based standard makes relay ie SIEMENS, ABB, GE, AREVA could be used for over flux protection, generally it is incorporated as one of the function in multifunction relay used for complete generator protection package. It has two V/Hz measuring stages with time delay and wide setting range: 0.2-9.6 V/Hz. Stage 1 is programmable for five different inverse time characteristics and definite time delay, settable 1-200 min. Stage 2 is definite time delayed. The relay provides a precise measurement of the relationship between voltage and frequency within the frequency range 5 -100 Hz. Here we are simulating over-excitation principle by using Matlab technique.

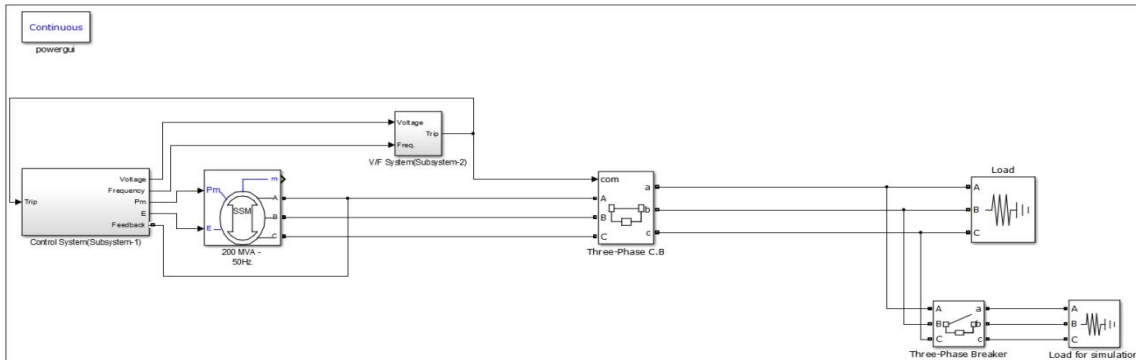
## IV. PROPOSED METHODOLOGY

As we came to know that over-flux protection is one of the primary protection for any generator and large step-up/generator transformer for the protection of core heating and inter laminar short circuit. Herewith I am trying to explain over flux phenomenon by adopting MATLAB Simulink procedure, here it is categorized in three basic block diagrams as mentioned below.

- a) Three phase Simulink diagram of machine
- b) Simulink subsystem for generator over-flux relay
- c) Simulink subsystem for turbine and generator excitation control

## a) Three phase diagram of machine:

With reference to figure-E generator is assumed as a dynamic model supplying power to three phase load through a three phase breaker and another one load block is also supplied through a three phase CB for initiating fault required for simulation. Here generator rating is assumed as 200 MVA, 132 KV, 50 HZ. Coupled with its prime-mover as turbine and equipped with excitation system. Subsequently two more subsystems are shown here as over-flux system and control system respectively.

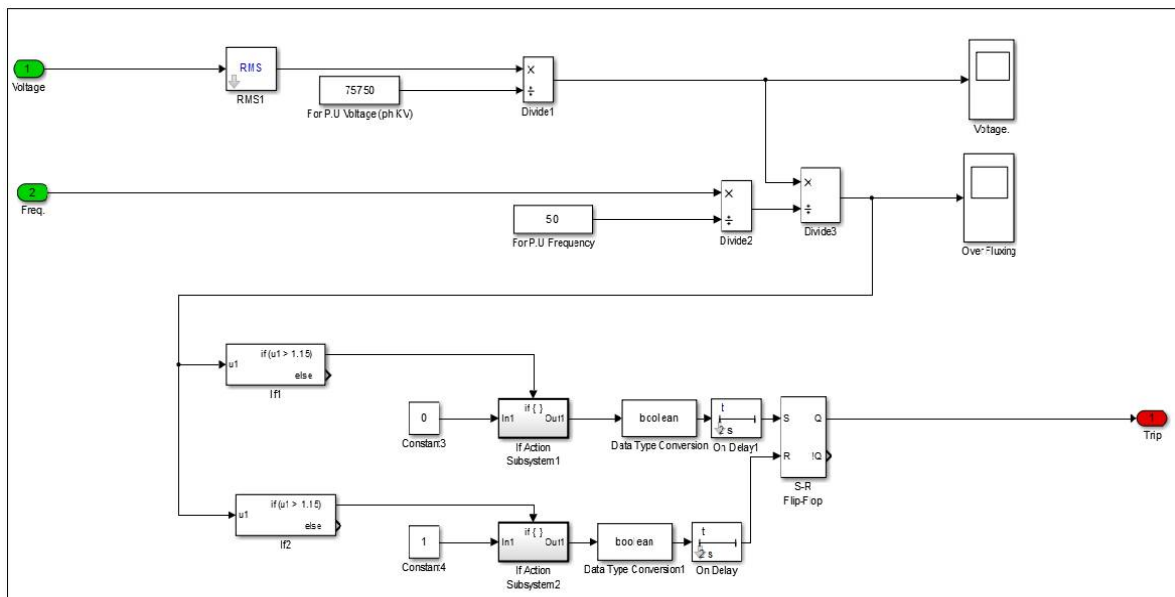


*Fig E-Three phase Simulink diagram of machine*

**b) Simulink sub-system for generator over flux relay:**

Voltage and frequency inputs are taken as input for this subsystem and calculate V/F for issuing trip signal. Voltage signal is converted into RMS values as these are in discrete form and given to scope after p.u conversion, for conversation we are using a divide block ie divide the actual voltage signal with phase value of generator voltage. Similarly frequency signal are converted into p.u, by dividing actual frequency signal by power frequency ie 50 Hz and given to divide-3 block which is equivalent V/F

signal given parallel to scope. We are using two IF blocks and further If V/F magnitude is less then set value(1.15) (<1.15) then Flip-flop output is 1 and load CB is in ON position, and further if V/F value crosses set point ie (>1.15) then Reset input at flip-flop is 1 and out-put trip signal becomes 0 after set delay of 2.0 sec and CB will trip and simultaneously Pm and E reduced to 0.



*Fig F-Simulink sub-system for over-flux relay*



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### c) Simulink sub-system for Turbine and Excitation control:

Voltage F/B is taken at IN-Point(1) and proportionate voltage signal comes at out point (1) and one voltage to frequency convertor block is used which gives proportionate frequency o/p at out point (2). Switch 1 is used here with following inputs, 1- proportionate frequency out, 2- clock ref, 3- 50 Hz ref input. Switch1 output is given to gain of 1/50 which further given to a summing point through integrator. Governor and turbine TF are assumed as  $(1/(2s+1))$  and  $(1/(s+1))$  respectively. Out- put of this TF through gain of 200e6 is given to switch2. Switch 2 has following inputs, 1- 185 MW power input, 2&3 has TF out- put which derived as mechanical power input to turbine (Pm). Excitation volt is derived from proportionate generator terminal voltage (132 KV) as E. Further trip output is given to product blocks 1 and 2 simultaneously to make Pm and E zero in the event of trip signal issued from relay.

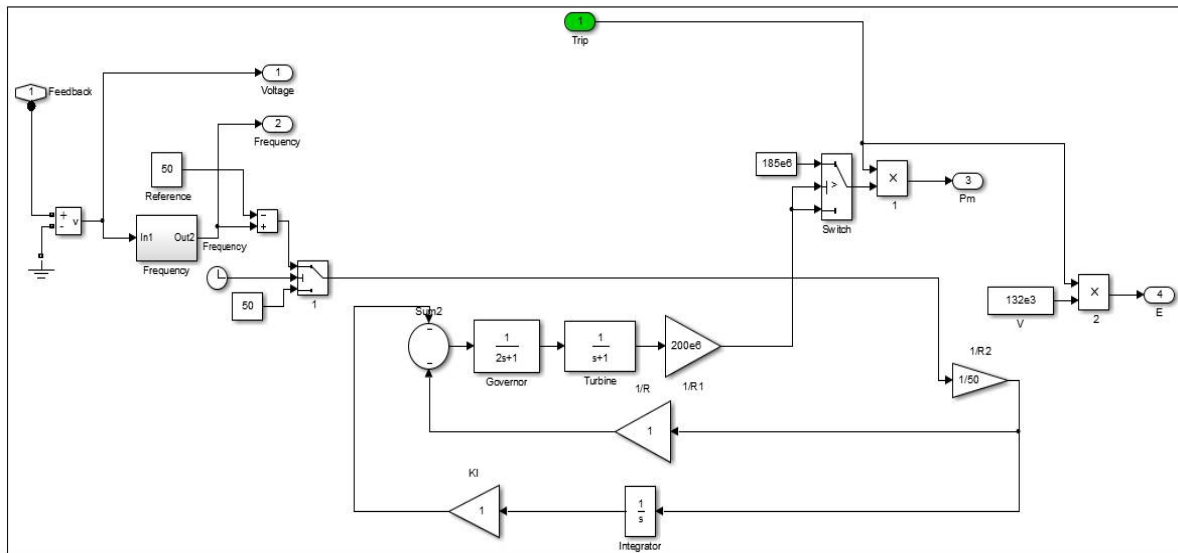


Fig G- Simulink sub-system-1 for Turbine and Generator Excitation control

## V. EXPERIMENTAL RESULTS

The results are shown in two parts as detailed below.

### a) V/F wave form of machine:

With reference to Fig-H, total simulation time in Matlab adjusted to 30.0 sec and fault initiated at 25.0 sec, and V/F magnitude reaches to its nominal value of 1.0 p.u in 14.0 sec and rises to 1.18 times at 25.0<sup>th</sup> sec and remains up to 27.0 sec, which clearly indicates the delay incorporated in Matlab of 2.0 sec after wards when trip signal issued to CB, V/F magnitude comes down to 0 instantaneously. Therefore fault clearing time is 2.0 sec. In the fig below over-flux magnitude shown in Y-axis and X-axis is the simulation time.

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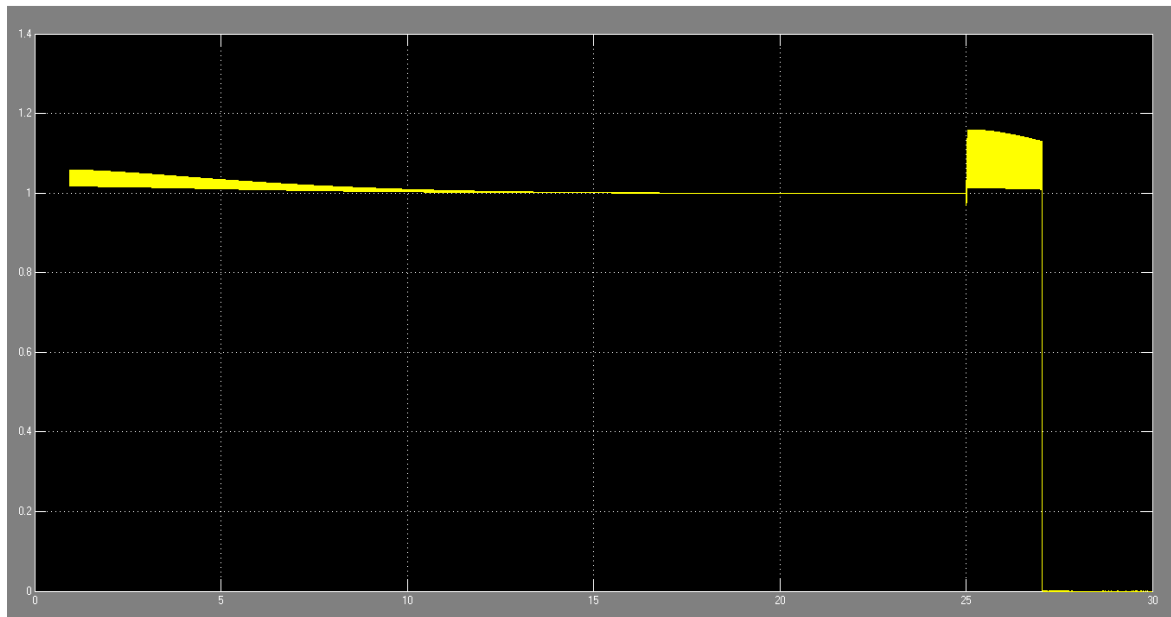


Fig H- Over-excitation curve for machine

## b) Voltage wave form of machine:

With reference to Fig-I, nominal machine voltage reaches at 12.0 Sec as generator is considered as dynamic source, when fault occurs at 25.0<sup>th</sup> sec voltage drops down to 0.88 pu and machine trips after set delay of 2.0 sec and terminal voltage comes down to instantaneously.

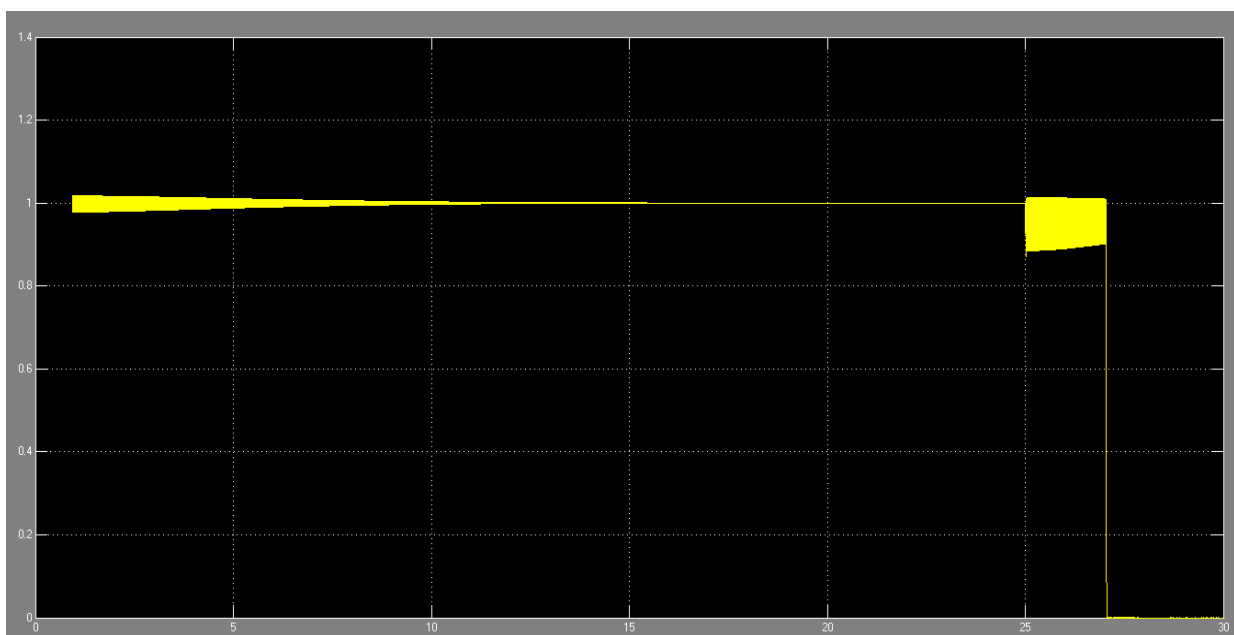


Fig I- Voltage profile of machine

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## VI. CONCLUSION

Though over-flux protection is one of the primary protections used for generators and large power transformer to protect generators and transformers from inter laminar short circuit and core overheating. Generally both IDMT and DT characteristic used for give an alarm and trip signal to shut off machine but here I am using only DT characteristic to explain its functionality.

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