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A NOVEL TECHNIQUE FOR SIMULATING THE HVLC IN MATLAB FOR CONTROLLING GROUND VOLTAGE

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ABSTRACT: This work is primarily concerned with the performance of tower base earthing systems under AC variable frequency and transient conditions. The work has involved the investigation into the performance of practical earthing systems, including tests on a full-size transmission tower base and corresponding calculation and numerical simulations. An extensive literature review of the performance of various types of electrodes under DC, AC and impulse currents is presented. In addition, a critical review of electrocution hazards from earthing systems was achieved.A full tower base, built for the purpose of earthing performance investigations, was used to evaluate the potentials around the tower footings and at the ground surface in the vicinity of the tower base. Using low magnitude variable frequency AC current injection, it was demonstrated experimentally that the surface potential around the tower base falls rapidly which may result in high step and touch voltages. This behavior is verified by using MATLAB software. The ground potential of the concrete and soil at different depths has been investigated and revealed that the potentials generated decrease with depth. In addition, DC earth resistance are carried out on earthing system components and their seasonal variation recorded. To mitigate the touch and step voltages in the vicinity of tower base, a voltage control ring applied. The investigation was computed where several parameters including such as, number and depth of the rings, the soil resistivity and the frequency. As for the low magnitude impulse current injection, it was demonstrated experimentally that the surface potential around the tower base falls rapidly along the four diagonal profiles which may result in high step and touch voltages. The ground potential distribution into the concrete and the soil at different depths under impulse energisation is investigated experimentally and revealed that the potentials generated decrease with depth. The current distributions into the tower base and one of the tower footings are also investigated. It was found that majority of the current dissipated into the footing.

I. INTRODUCTION

1.1 Transmission line

In communications and electronic engineering a transmission line is a specialized cable or other structure designed to carry alternating current of radio frequency, that is, currents with a frequency high enough that their wave nature must be taken into account. Transmission lines are used for purposes such as connecting radio transmitters and receivers with their antennas, distributing cable trunk lines routing calls between telephone switching centers, computer network connections and high speed computer data buses. This article covers two-conductor transmission line such as parallel line (ladder line), coaxial cable, Stripline, and microstrip. Some sources also refer to waveguide, dielectric waveguide, and even optical fiber as a transmission line, however, these lines require different analytical techniques and so are not covered by this article see Waveguide (electromagnetism).

1.2 Overview of transmission line

Ordinary electrical cables suffice to carry low frequency alternating current (AC), such as mains power, which reverses direction 100 to 120 times per second, and audio signals. However, they cannot be used to carry currents in the radio frequency range or higher, which reverse direction millions to billions of times per second, because the energy tends to radiate off the cable as radio waves, causing power losses. Radio frequency currents also tend to reflect from discontinuities in the cable such as connectors and joints, and travel back down the cable toward the source. These reflections act as bottlenecks, preventing the signal power from reaching the destination. Transmission lines use specialized construction, and impedance matching, to carry electromagnetic signals with minimal reflections and power losses. The distinguishing feature of most transmission lines is that they have uniform cross sectional dimensions along their length, giving them a uniform impedance, called the characteristic impedance, to prevent reflections. Types of transmission line include parallel line (ladder line, twisted pair), coaxial cable, stripline, and microstrip. The higher the frequency of electromagnetic waves moving through a given cable or medium, the shorter the wavelength of the waves. Transmission lines become necessary when the length of the cable is longer than a significant fraction of the transmitted frequency's wavelength. At microwave frequencies and above, power losses in transmission lines become excessive, and waveguides are used instead, which function as "pipes" to confine and guide the electromagnetic waves. Some sources define waveguides as a type of transmission line;[however, this article will not include them. At even higher frequencies, in theterahertz, infrared and light range, waveguides in turn become lossy, and optical methods, (such as lenses and mirrors), are used to guide electromagnetic waves. The theory of sound wave propagation is very similar mathematically to that of electromagnetic waves, so techniques from transmission line theory are also used to build structures to conduct acoustic waves; and these are called acoustic transmission lines.For the purposes of analysis, an electrical transmission line can be modelled as a two-port network (also called a quadrupole network), as follows:

Fig1.1: Two Port representation of Line

In the simplest case, the network is assumed to be linear (i.e. the complex voltage across either port is proportional to the complex current flowing into it when there are no reflections), and the two ports are assumed to be interchangeable. If the transmission line is uniform along its length, then its behaviour is largely described by a single parameter called the characteristic impedance, symbol Z_0. This is the ratio of the complex voltage of a given wave to the complex current of the same wave at any point on the line. Typical values of Z_0 are 50 or 75 ohms for a coaxial cable, about 100 ohms for a twisted pair of wires, and about 300 ohms for a common type of untwisted pair used in radio transmission. When sending power down a transmission line, it is usually desirable that as much power as possible will be absorbed by the load and as little as possible will be reflected back to the source. This can be ensured by making the load impedance equal to Z_0, in which case the transmission line is said to be matched.

Fig1.2: A transmission line is drawn as two black wires

A transmission line is drawn as two black wires. At a distance x into the line, there is current I(x) travelling through each wire, and there is a voltage difference V(x)between the wires. If the current and voltage come from a single wave (with no reflection), then $V(x) / I(x) = Z_0$, where Z_0 is the characteristic impedance of the line. Some of the power that is fed into a transmission line is lost because of its resistance. This effect is called ohmic or resistive loss (see ohmic heating). At high frequencies, another effect called dielectric loss becomes significant, adding to the losses caused by resistance. Dielectric loss is caused when the insulating material inside the transmission line absorbs energy from the alternating electric field and converts it to heat (see dielectric heating). The transmission line is modelled with a resistance (R) and inductance (L) in series with a capacitance (C) and conductance (G) in parallel. The resistance and conductance contribute to the loss in a transmission line.The total loss of power in a transmission line is often specified in decibels per metre (dB/m), and usually depends on the frequency of the signal. The manufacturer often supplies a chart showing the loss in dB/m at a range of frequencies. A loss of 3 dB corresponds approximately to a halving of the power. High-frequency transmission lines can be defined as those designed to carry electromagnetic waves whose wavelengths are shorter than or comparable to the length of the line. Under these conditions, the approximations useful for calculations at lower frequencies are no longer accurate. This often occurs with radio, microwave and optical signals, metal mesh optical filters, and with the signals found in high-speed digital circuits.

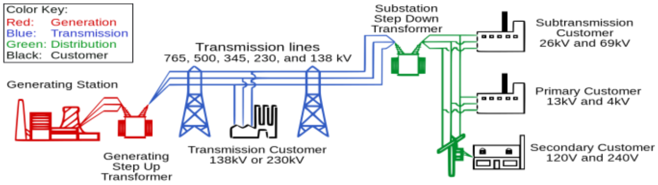

Fig1.3 : Diagram of an electric power system; transmission system is in blue

Most transmission lines are high-voltage three-phase alternating current (AC), although single phase AC is sometimes used in railway electrification systems. High-voltage direct-current (HVDC) technology is used for greater efficiency at very long distances (typically hundreds of miles (kilometers)), in submarine power cables (typically longer than 30 miles (50 km)), and in the interchange of power between grids that are not mutually synchronized. HVDC links are also used to stabilize and control problems in large power distribution networks where sudden new loads or blackouts in one part of a network can otherwise result in synchronization problems and cascading failures. During a lightning strike, the electrical power system is subjected to a very large current with a fast rise time. Lightning strikes to tall structures such as transmission towers can produce voltages so high that insulation fails and electrical equipment can be destroyed. Such strikes produce an earth potential rise in the surrounding soil which can endanger persons who happened to there at the time. Thus, high voltage transmission and distribution systems require lightning protection and insulation co-ordination schemes to protect personnel and power system equipment from danger and damage. A fundamental factor that determines the effectiveness of these schemes is an efficient connection to earth. For safety, an appropriate design of earthing system limits the step and touch voltages to be within the values permitted by national and international standards.

1.3 Earthing systems

The earthing system of electricity substations and transmission lines is required to ensure (i) electrical safety for persons working within or near the substation or in proximity of transmission towers and (ii) reduce damage to equipment while reducing disturbances to power system operations. Though high voltage transmission and distribution systems are protected from lightning strikes, the effectiveness of the lightning protection depends very much on its connection to earth.

II. LITERATURE SURVEY

L. Gyugyi Proposed with dynamic var compensation of electric power systems, applying power electronics for reactive power generation and control. After an overview of the emergence and status of modern, solid-state var compensators in utility and industrial applications, the first part of the paper explains how dynamic var compensation increases transmittable power by providing voltage support, transient stability improvement, and power oscillation damping in electric power transmission systems. Subsequent sections describe the methods of reactive power generation and control using thyristor-controlled reactors, with fixed and thyristorswitched capacitors, or modern gate turn-off (GTO) power converters that can function without ac capacitors or reactors. The last part of the paper summarizes the control structure and operation to provide the desired characteristics and performance in power system applications.

M. H. Hague Proposed a new control strategy of shunt flexible ac transmission system (FACTS) devices to improve the first swing stability limit of a simple power system. It is shown that the speed based bang-bang control (BBC) is unable to use the entire decelerating area in maintaining stability. The proposed control strategy improves the stability limit first by maximizing the decelerating area and then fully utilizing it in counterbalancing the accelerating area. This requires to continue the operation of shunt FACTS devices at full capacitive rating until the machine speed reaches a reasonable negative value during the first return journey. Afterwards, the control can be switched to continuous type to improve system damping in subsequent swings. The proposed control strategy is then applied to both static var compensator and static synchronous compensators placed in a single machine infinite bus system. The same control strategy is also used for some faults in a multimachine system. In both the systems, it is found that the proposed control can provide significantly higher stability limit than that of the BBC. The mechanism of improving the stability limit is also described.

A. E. Hammad Proposed Today's electric power systems are continually increasing in complexity due to interconnection growth, the use of new technologies, and financial and regulatory constraints. Sponsored by the Electric Power Research Institute, this expert engineering guide helps you deal effectively with stability and control problems resulting from these major changes in the industry. Power System Stability and Control contains the hands-on information you need to understand, model, analyze, and solve problems using the latest technical tools. You'll learn about the structure of modern power systems, the different levels of control, and the nature of stability problems you face in your day-to-day work. The book features a complete account of equipment characteristics and modeling techniques. Included is detailed coverage of generators, excitation systems, prime movers, ac and dc transmission, and system loads - plus principles of active and reactive power control, and models for control equipment. Different categories of power system stability are thoroughly covered with descriptions of numerous methods of analysis and control measures for mitigating the full spectrum of stability problems.

N. G. Hingorani, and L. Gyugyi Proposed The flexible ac transmission system (FACTS) is a new technology, based on power electronics, to enhance power system capability through the ability of high-speed electronic control of ac transmission line parameters. Written by two pioneers in FACTS technology, Hingorani and Gyugyi, they present a very useful guide for power electronic application engineers, which emphasizes explanations of the physical principles rather than detailed mathematical theory. This book gives the reader a broad understanding of the entire FACTS technology and enables them to apply this information towards advancing this technology.

P. Kundur Proposed a fundamental analysis of the application of static VAr compensators (SVC) for stabilizing power systems. Basic SVC control strategies are examined in terms of enhancing the dynamic and transient stabilities, improving timeline transmission capacity and damping power oscillations. Synchronizing and damping torque contributions of the SVC are determined for different controls. The analysis is supplemented by digital simulations for a simple practical example. Deficiencies of available control policies are demonstrated and a new concept, based on optimal control, is developed. In power systems, controlling the voltage throughout the network, as well as damping power and frequency oscillations, presents a continuous challenge to power system planners and operators. In order to run the integrated generation transmission-distribution system in the most economic and reliable fashion and prevent it from collapse under all possible operating conditions, new control techniques are always in great demand.

K. R. Padiyar Proposed the modelling of IPFC with 12-pulse, three-level converters and investigates the subsynchronous-resonance (SSR) characteristics of IPFC for different operating modes. The analysis of SSR is carried out based on eigenvalue analysis and transient simulation of the detailed system. It is illustrated with the help of a case study on a system adapted from the IEEE Second Benchmark Model. The analysis uses both – model (neglecting harmonics in the output voltages of VSCs) and the three-phase model of VSCs using switching functions. While the eigenvalue analysis and controller design is based on the – model, the transient simulation considers both models. The interline power-flow controller (IPFC) is a voltage-source-converter (VSC)-based flexible ac transmission system (FACTS) controller for series compensation with the unique capability of power-flow management among the multiline transmission systems of a substation. The reactive voltage injected by individual VSCs can be maintained constant or controlled to regulate active power flow in the respective line. While one VSC regulates the dc voltage, the others control the reactive power flows in the lines by injecting series active voltage.

K. R. Padiyar, and R. K. Verma Proposed with the application of damping torque technique to examine the efficacy of various control signals for reactive power modulation of a midpoint located Static Var System (SVS) in enhancing the power transfer capability of long transmission lines. A new auxiliary signal designated Computed Internal Frequency (CIF) is proposed which synthesizes internal voltage frequency of the remote generator from electrical measurements at the SVS bus. It is demonstrated that this signal is far superior than other conventional auxiliary control signals in that it al.lows full utilization of the network transmission capacity. The damping torque results are correlated with those obtained from eigenvalue analysis. extend the stability limit and improve system damping when connected at the midpoint of a long transmission line. While an SVS with pure voltage control may not adequately contribute to system damping, a significant enhancement in the same is achieved when SVS reactive power is modulated in response to auxiliary control signals superimposed over its voltage control loop.

III. OBJECTIVE

In this thesis when a high voltage transmission line crosses remote areas where no distribution network is available, it is possible to tap power from the overhead ground wires (OHGW) protecting the line against lighting strokes. Hydro-Quebec developed the IVACE technology to provide power to telecommunication towers located in the northern part of its network. This Sim Power Systems model illustrates the principle of operation of an IVACE-based 25 kW power supply connected to one of the two OHGW of a 850 KV transmission line.

3.1 Technique

When a section OHGW is disconnected from ground, an AC voltage at the fundamental frequency (60 Hz or 50 Hz) is induced on this OHGW by capacitive coupling with the three phase conductors. Higher voltages are obtained with tower configurations yielding large asymmetries between OHGW and phase conductors. The maximum available power is proportional to the length of isolated OHGW. For typical 850-kV line parameters (as those used in this model), isolating a 4 km section of one of the two OHGW allows tapping 25 kW of power. In order to compensate voltage drop due to the OHGW capacitive impedance, the regulator must absorb a reactive power depending on load current. Ideally, the regulator V-Ix characteristic (where V= regulated voltage, Ix= reactive current flowing into the regulator) must be flat so that regulated voltage does not depend on load.

IV. SIMULATION MATLAB (MATRIX LABORATORY)

It is a multi-paradigm numerical computing environment and fourth generation programming language. A proprietary programming language developed by MathWorks, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, Fortran and Python. Although MATLAB is intended primarily for numerical computing, an optional toolbox uses the MuPAD symbolic engine, allowing access to symbolic computing abilities. An additional package, Simulink, adds graphical multi-domain simulation and model-based design for dynamic and embedded systems.

V. RESULT AND SIMULATION

In order to achieve each component is added in simulation through matlab 2010 by simulink.

5.1 SIMULATION OUTPUT

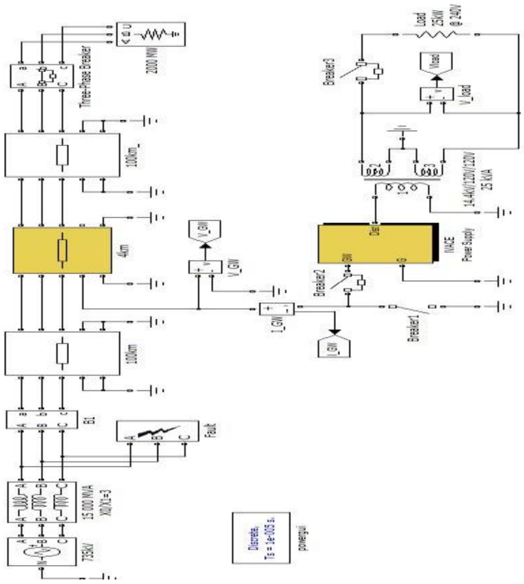

Fig 5.1 : Layout of modelling of each component of proposed system – Upper Part

In order to compensate voltage drop due to the OGW capacitive impedance, the regulator must
absorb a reactive power depending on load current. Ideally, the regulator V-Ix characteristic where,

V= regulated voltage,
Ix= reactive current
flowing into the regulator must be flat so that regulated voltage does not depend on load.

5.2 OGW Power Supply Regulator

The regulator connected on the 500 V winding of the coupling transformer uses only passive components: a magnetic device named IVACE acting as a non-linear inductance and a few RLC components. This regulator does not rely on control system or power electronics (with the exception of four diodes). It is therefore extremely robust. Detailed description is given in as well as in patents obtained in various countries around the world. The IVACE components are shown in yellow. IVACE consists of two 500 V /515 V transformers Tsat1 and Tsat2 (ratio 1:1.03). Primary windings are series connected through a diode rectifier and rectified current is sent back in reverse directions to the two secondary windings. When the transformer ratios and gaps are properly adjusted this set-up gives a quasi-flat saturation characteristic with a flux knee point at 1 pu. When input voltage is large enough the two transformers will saturate alternatively in positive and negative direction during one cycle. In order to decrease IVACE current rating, a parallel inductor L1= 13.26 mH is connected in parallel. This fixed inductance absorbs most of the regulator reactive current (100 Arms @ 500 V), the rest being absorbed by IVACE. The parallel capacitor C1 is used to tune sharing of current between the fixed reactance branch (L1-C1) and IVACE so that its regulation range corresponds to the nominal load. The R2-L2-C2 damping filter tuned at 60-Hz is used to prevent harmonic and subharmonic resonances as well as for fine tuning the regulated voltage. R3-C3 is a conventional snubber protecting the diode bridge.

The idealized overall V-I characteristic (IVACE + L1-C1 branch) is as shown by the red curve on Figure 5.2.

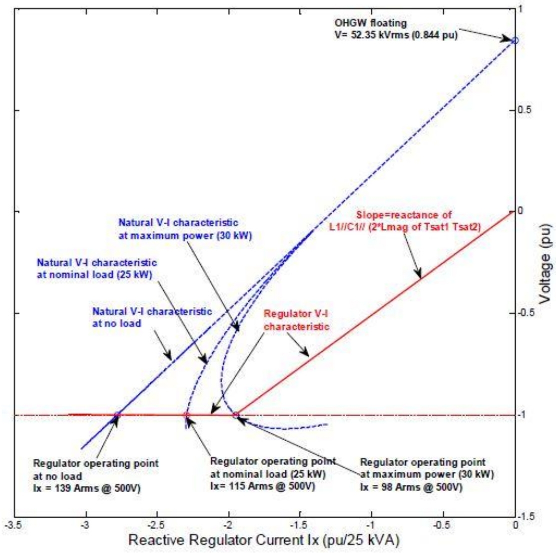

Figure 5.2 Theoretical VI characteristics

Figure 5.2 shows the natural V-I characteristics of the OGW capacitive source (blue curves) connected to an inductive current source. V-I characteristics are shown for three load conditions:

1) no load 2) nominal load (25 kW) and 3) theoretical maximum power (30.3 kW). These characteristics were obtained with a natural OGW voltage of 52.35 kV, representing 0.844 pu of the regulated voltage (62 kV) and a capacitance of 26 nF (400 µF seen from 500 V). The intersection of the natural OGW characteristics (in blue) and regulator characteristic (in red) determines the regulator operating points. Note that the operating voltage is -1 pu whereas the natural voltage (voltage at zero current) is +0.844 pu. This negative sign indicates that at no load the phase angle of the regulated voltage is 180 degrees out of phase with natural voltage obtained without regulator.

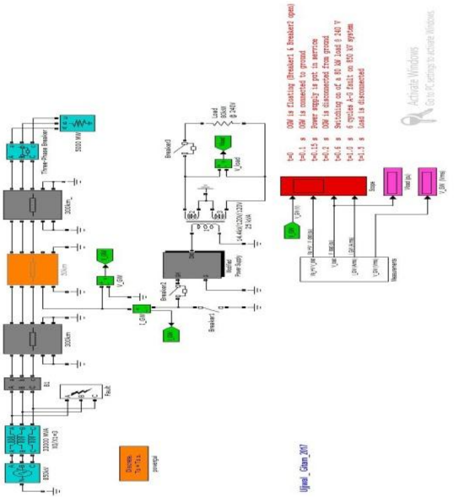

Fig 5.3 : Layout of modelling of each component of proposed system – Lower Part

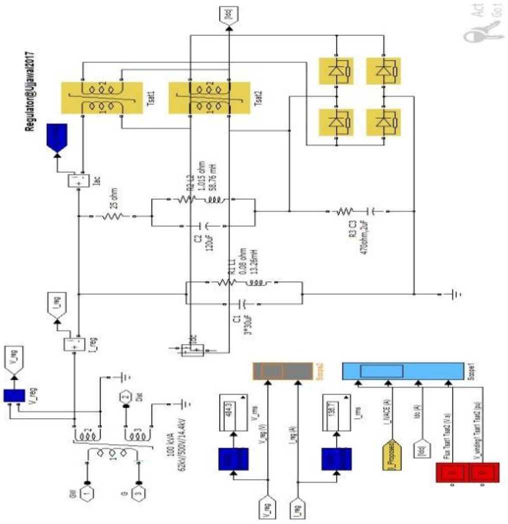

Fig 5.4 : Layout of proposed work

When IVACE used for proposed modeling for high voltage transmission line crosses remote areas which has no distribution network is available.The proposed model is sufficient to show by graph that it tap power from the overhead ground wires (OGW) that is protecting the line against lighting strokes. This proposed System model illustrates the principle of operation of an IVACE-based on fixed power supply connected to one of the two OGW of a fixed transmission line has best suited for developing the transmission network. Modification in basic IVACE technique by capacitive coupling with the three phase conductors in proposed model enhanced the present capacity of exsiting services.

5.3 Implementation Process

Run the proposed model that is based on IVACE-regulated power supply connected on a 50 km OGW of a 850-KV transmission line. Observe the following sequence of events on the Scope.

- At t=0 sec, the IVACE power supply is disconnected and the OGW is floating (Breaker1 and Breaker2 are open). The OGW voltage displayed on trace 1 is 51.2 kV rms (72.4 kV peak).This voltage is slightly lower than its nominal value (52.35 kV) because voltage of phase conductors is lower than its 850kV nominal value (0.981 pu).

- At t=01 sec, the ground wire is connected to ground by closing Breaker1. The short circuit current shown on trace 4 is 0.5 A rms. The capacitive reactance of the OGW is therefore Xc=51.2e3/0.5=102.4 kohms at 60 Hz, corresponding to a capacitance C=26 nF.

- At t=0.15 sec, the IVACE power supply is put in service by closing Breaker2 while the OGW is still short-circuited to ground.

- At t= 0.2 sec, short circuit is removed by opening Breaker1. The power supply starts to operate at no load (Breaker 3 is open). After a transient period of approximately 0.2 sec load voltage shown on trace 3 stabilizes at 0.97 pu.

- At t= 0.6 sec, the 240 V 25 kW load is switched on by closing Breaker3. Load voltage momentarily drops to 0.65 pu and then the regulator restores nominal load voltage (1.0 pu). Regulator response time is approximately 0.2 sec.

- At t= 1.0 sec, a 6-cycle phase-to-ground short circuit is applied on phase A of the 850 kV transmission line. As phase A voltage falls to zero, the induced voltage on OGW increases because of higher asymmetries in the induced voltages (only B and C phases now induce voltage on OGW). Resulting load voltage momentarily increases to 1.5 pu. Then load voltage is regulated close to its nominal value (0.95 pu) even if fault has not yet been eliminated.

- At t= 1.1 sec, the phase-to-ground fault is eliminated. Load voltage momentarily drops to 0.35 pu and then the regulator restores nominal load voltage (1.0 pu).

- At t= 1.5 sec, the 25 kW is switched off. A transient load overvoltage of 1.57 pu is observed on distribution voltage (magenta trace of scope input 2). Then the regulator restores voltage to its 0.97 pu after 0.15 sec. You can also observe additional signals inside the IVACE Power Supply subsystem.

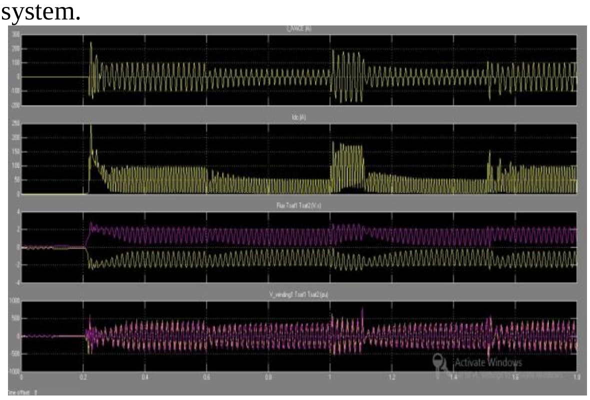

Fig 5.5: Scope1 displays currents flowing into ac side and dc side of IVACE regulator as well fluxes and voltages of Tsat1 and Tsat2.

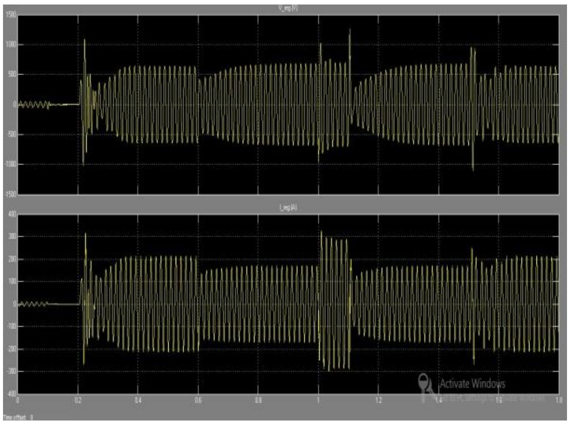

Fig 5.6: Scope2 shows regulator voltage and current. When simulation is completed waveforms are stored respectively in Scope1Data and Scope2Data structures. This allows you to perform a harmonic analysis of various waveforms (by using the FFT analysis tool of the powergui block).

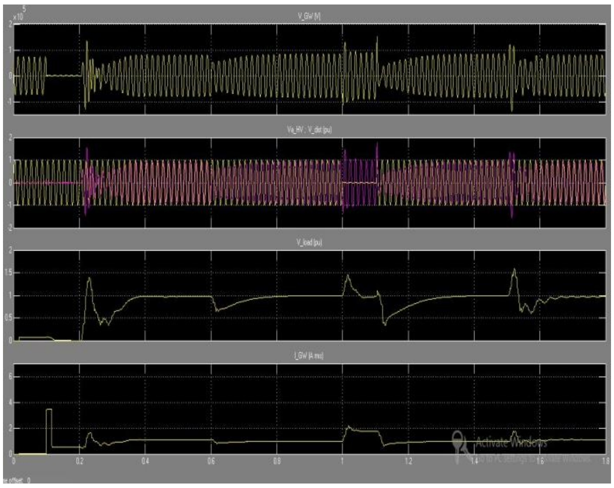

Fig 5.7 : For example, an analysis of the V_reg regulator voltage stored in Scope3 Data reveals that the total harmonic distortion (THD) of voltage is 6.5% at no load and 4.7 % at nominal load with main contribution to THD coming from 3 rd harmonic.

An analysis of the I_reg signal reveals that the magnitude of fundamental current at no load and at nominal load are respectively 192 A peak (136 A rms) and 151 A peak (107 A rms). These values compare well with the theoretical values given on figure 5.2 (139 A rms and 115 A rms). Conductor data and tower geometry which have been used to generate the electrical transmission line parameters (5x5 R, L, C matrices) are included.

5.4 Comparative Study

	Earlier Model	Proposed Model
Technology	IVACE	IVACE
Dependent Circuitory	Simple Regulator	capacitive coupling with the three phase conductors
Load Capacity	loads ranging from about 300 W to 300 kW	loads ranging about 300 W 2000 MW
Transmission Line	69 KV to 120-kV	850 kV

As comparative study shows the enhancement in load capacity and voltage capacity significantly with inclusion of capacitive coupling with IVACE model.

VI. CONCLUSION & FUTURE WORK

Important areas of future research work on tower base earthing systems include (i) the installation a ring electrodes of different diameters and depths around each tower footing and (ii) further experimental studies to clarify the conduction mechanisms of earth electrodes under high magnitude impulse current. The objective of the experimental work on ring electrodes for controlling ground voltage gradient would be to mitigate step and touch voltages in the proximity of tower footings. It is proposed that conduction mechanism investigations would be based on high voltage laboratory tests and high voltage tests on practical earth electrodes at the Cardiff University outdoor earthing test facility at Llanrumney.

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