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Emulations of Overvoltage and Overcurrent Relays In Transmission Lines

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***Abstract*— An "Over Voltage Relay" is one of the protective relays which operates when the voltage exceeds a preset value. In a typical application the over voltage relay is used for over voltage protection, which is connected to a potential transformer, and calibrated to operate at or above a specific voltage level. An "Under Voltage Relay" and an "Over Current Relay" are also protective relays which operate when the voltage is reduced, or the current is increased below or above a preset value. In a typical application these relays are connected to potential transformers, and calibrated to operate at, above or below a specific voltage or current levels.**

The emulator used in paper simulated experiments of all three types of relays mentioned above. The transmission line emulator used in this paper is an HVAC transmission line of length of 180 km. The transmission line of the emulator can be used as a 3-phase transmission line of 180 km length or as a single-phase transmission line of 540 km long. This transmission line in the emulator is divided into 6 π sections and each π section is 30 km long. The line inductance of the transmission line of the emulator is examined for every 30 km and the line capacitance is examined for every 15 km. The line parameters of the emulator (RLC) for the 400kV transmission line are: 0.02978 Ω/km, 1.06 mH/km and 0.0146 µF/km, respectively.

Keywords: over voltage relay, under voltage relay, over current relay.

I. INTRODUCTION

In the early days, generation, transmission, and distribution of electricity were in most cases DC current. DC systems posed a problem which is the fact that the level of the voltage was difficult to change. However, this could be achieved by using rotating machines, but the costs will be much greater. Nowadays AC power systems are used more often than DC systems. At the production power station, electricity is transmitted at very high voltages to reduce losses and consequently it must be stepped down at the substation so that it can be used by the different customers. In the design and operation of transmission lines, it is a fact that the main factors of these lines are the voltage drop, the losses of the lines and the efficiency of the transmission lines.

The emulator used in this paper can be used to investigate simulating experiments which cover all design aspects of high voltage transmission lines. In previous papers (1) and (2) the emulator was used to investigate the Ferranti effect, the ABCD parameters of 400 kV HVAC transmission line and the surge impedance loading. Paper (2) investigated the shunt reactor compensation, shunt capacitor compensation, and series reactor compensation. This paper will present the results of the emulations of over voltage, under voltage and over current relays of the transmission lines under heavy loading conditions.

Transmission lines are a vital part of the electrical distribution system, as they provide the path to transfer power between generation and load. Transmission lines operate at voltage levels from 69kV to 765kV and are ideally and tightly interconnected for reliable operation. Factors like de-regulated market environment, economics, right of way clearance and environmental requirements have pushed utilities to operate transmission lines close to their operating limits. Any fault, if not detected and isolated quickly will cascade into the system wide disturbance causing widespread outages for a tightly interconnected system operating close to its limits. Transmission lines protection systems are designed to identify the location of faults and isolate only the faulted section. The key challenge to the transmission line protection lies in reliably detecting and isolating faults without compromising the security of the system.

II. FACTORS INFLUENCING LINE PROTECTION

The high-level factors influencing line protection include the criticality of the line in terms of load transfer and system stability, fault clearing time requirements for system stability, line length, the system feeding the line, the configuration of the line, the number of terminals, the physical construction of the line, the presence of parallel lines, the line loading, the types of communications available, and failure modes of various protection equipment. The more detailed factors for transmission line protection directly address dependability and security for a specific application. The protection system selected should provide redundancy to limit the impact of device failure, and backup protection to ensure dependability. Reclosing may be applied to keep the line in service for temporary faults, such as lightning strikes. The maximum load current level will impact the sensitivity of protection functions and may require adjustments to protection functions settings during certain operating circumstances. Single-pole tripping applications affect the performance requirements of distance elements, differential elements, and communications schemes. The physical construction of the transmission line is also a factor in protection system applications. The type of conductor, the size, and spacing of conductors determines the impedance of the line and the physical response to short circuit conditions as well as line charging current. In addition to this, the number of line terminals determines load and fault current flow, which must be accounted for by the protection system. Parallel lines also affect relaying as mutual coupling influences the ground current measured by protective relays. The presence of tapped transformers on a line or reactive compensation devices such as series capacitor banks or shunt reactors also influences the choice of protection system and the actual protection device settings. It is currently very common for emulations and simulation to be used as tools to examine rather difficult practical experiments of transmission lines.

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III. Transmission Line Protection Relays

The main purpose of transmission protection relays is to identify the faults of the location. These relays are also used to identify the type of faults in transmission lines. Transmission line protections are based on the use of relays of different types of relay systems which are used to protect transmission lines. These include protective relays which function to detect the fault and to initiate the appropriate control signal such as the tripping signal. Regulating relay is a device which manages the operation of the load of tap changer on the transformer. Reclosing and synchronizing relays are programmable relays where the function initiates a sequence of actions leading to the automatic reclosing of the circuit breaker. Auxiliary Relays assists other relays by applying supplementary actions.

The actual transmission lines unit and the measurement and protection units are shown in figure 1 and 2 respectively (12).

1-OVER CURRENT RELAYS

The aim of this experiment is to study the operation of over current relay using the high voltage Transmission Line Analyzer. An "Over Current Relay" is one of the protective relays which operates when the load current exceeds a preset value. In a typical application, this relay is used for over current protection, connected to a current transformer, and calibrated to operate at or above a specific current level. Over current relays are the cheapest type of line protection. There are three types of overcurrent relays that are commonly used. These are time-delay overcurrent (TDOC), instantaneous overcurrent relays (IOCR) and directional overcurrent relays (DOCR). Overcurrent relays are quite difficult in practice and these difficulties arise when coordination, selectivity, and speed are implicitly essential. The settings which need to be changed usually require changes to the configurations of the system. Furthermore, they are not able to distinguish between fault and load currents and because of this when they are used to protect against faults, they become useful only if the minimum value of the fault current becomes bigger than the current at full load. On the other hand, they are efficiently used in sub-transmission systems as well as radial distribution systems. The reason for this is that the faults of these systems do not affect stability of the system and consequently there is no need for protection at high speeds. The use of TDOC relays is mainly in radial systems and in such cases, they are used only for phase and ground protections. In these situations, they are usually of two-phase relay and one ground relay which will protect the line from all phase and ground faults and at the same time minimizes the number of relays which are used in the system. However, if a third phase relay is added to the system, it will act as another alternative fault protection. This is viewed as two relays for each type of fault, and in most cases, it is the preferred option. These systems are used in sub-transmission lines and in industrial systems because the cost is much lower. As the fault arises closer to the source, the fault current becomes bigger, but the tripping of the relay takes a longer time and, in such cases, TDOC cannot be used just by itself. As shown in figure 3 an instantaneous overcurrent relay must be added to provide better protection of the system. In such situations the fault current decreases because the fault is now close to the end of the line. In this case, the instantaneous relay is used till the point just before the beginning of the following bus. The relay in this case will not protect against faults after the end of the line even though it will provide for almost all of the line. Figure 3 shows this system of protection relay.

Figure 1. Transmission line unit

Figure 2.Measurement and protection unit

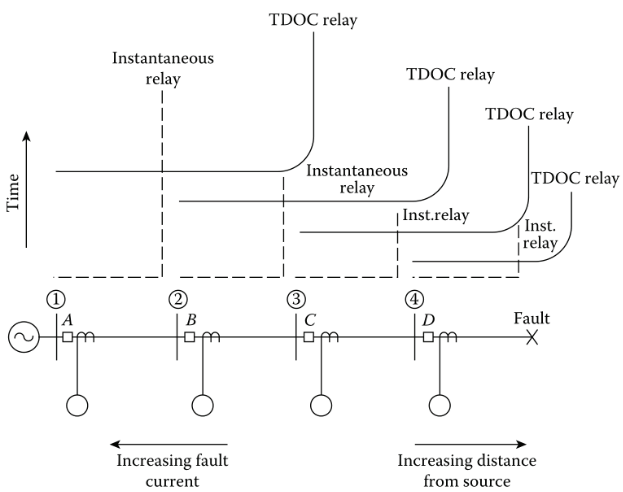

Figure 3. Connections of overcurrent relays (13)

When it is essential for fault tripping to be in one direction only and if there are many source circuits, it becomes imperative to use directional overcurrent relays. This is used to coordinate between all the relays of the system so that a fault can be detected more easily. If this methodology is not followed, coordination becomes almost impossible.

In this system two inputs are needed which are the operating current and a reference value which will not change with the position of the fault. If phase relays are used, the reference value in this case is the voltage at the position of the

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relay. In such systems, the neutral current i.e., the current in the neutral of star-connection power transformer is taken as a directional reference value. The autotransformer is varied to change the voltage applied at the sending end and the load is connected at the receiving end. When 80% of a set current is reached, the emulator indicates that and shows the reached level of current. The current value is gradually increased using the autotransformer until it becomes bigger than the set value. After this the relay timer starts and when the set time is reached, the relay trips and the emulator instantly indicates this value. The connections of over current relays are shown in figure 4 and the initial readings of the over current relay are shown in figure 5. The readings of the sending and the receiving ends of the transmission line is shown in figure 6 and the open and short circuit readings are shown in figure 7.

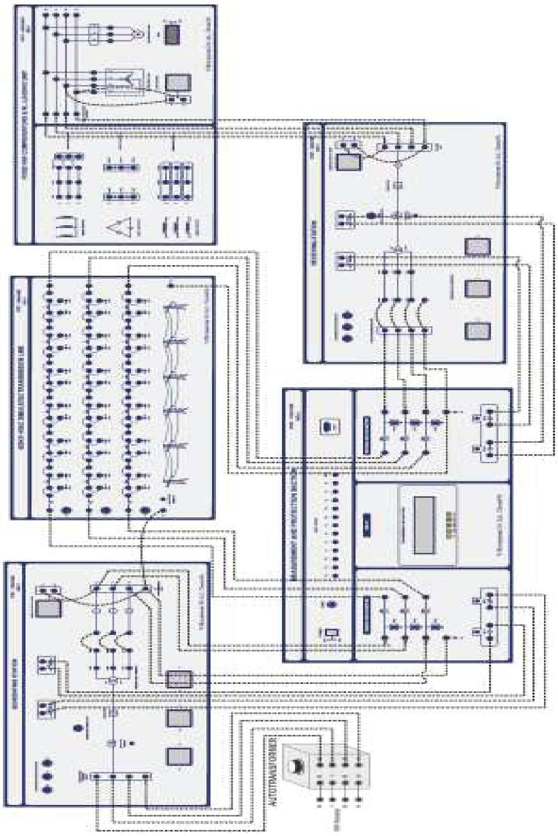

Figure 4. Connections of Over current relay

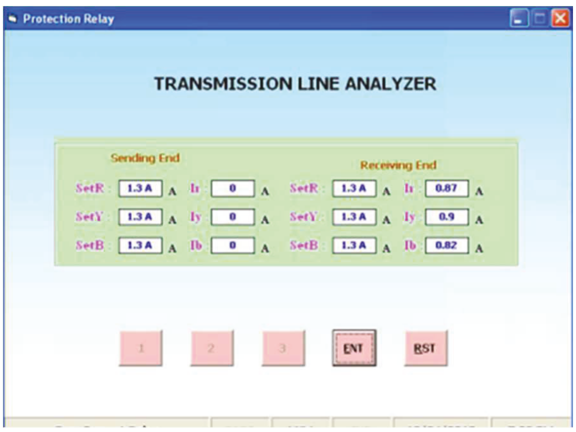

Figure 5. Initial readings of over current relay

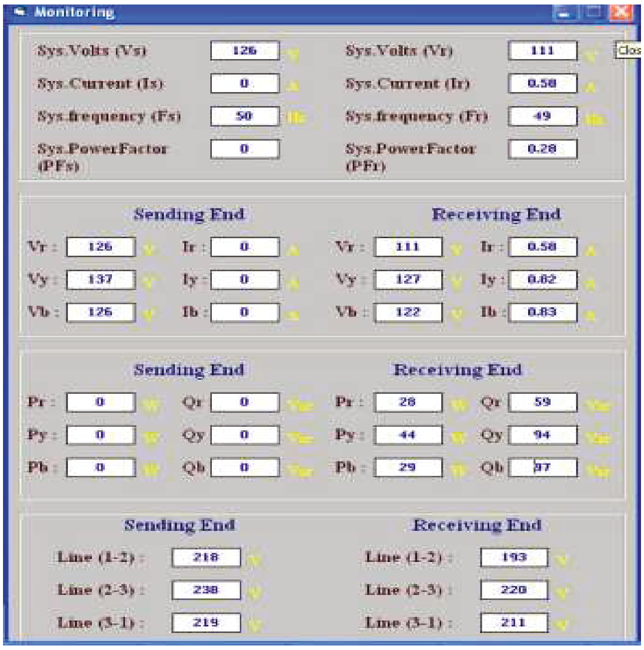

Figure 6. Sending and receiving readings of the emulator

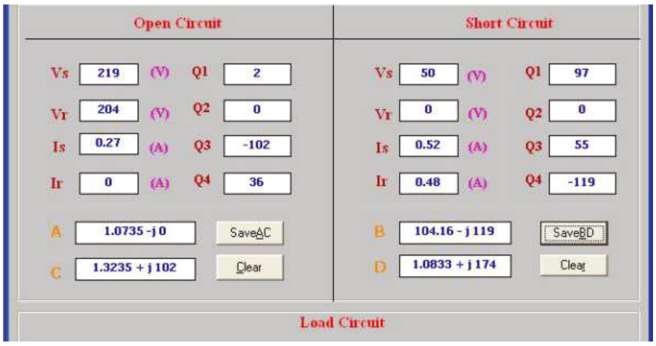

Figure 7. Readings of the open and short circuit of the emulator

2-OVER VOLTAGE RELAY

The aim of this experiment is to study the operation of over voltage relay using High Voltage Transmission Line Analyzer. Overvoltage is caused by an increase in voltage for short time in power systems which is commonly named the surge or transients voltage. The stress resulting from this voltage can damage transmission lines and the different parts and equipment which are connected to the system. The main two types of over voltage in power systems are those caused by external reasons and those caused by internal reasons. At high frequency, transient over voltages are generated and these result from switching of the load as well as lightning. This can also happen at medium frequency when energizing capacitors at low frequency. Over voltage which is caused by lightning strikes is a surge that is not related to the actual voltage of the transmission line. The cause of this could be of many reasons which include over voltages induced electromagnetically because of lightning discharge which occurs near the transmission line. These include side strikes, lightning strikes and induced voltages which occur because of changes in the atmosphere which can be seen along all the length of the transmission line. There are also voltages which are induced electrostatically because of the existence of clouds which are charged near the transmission line areas. In addition to this, there are also over voltages which are induced electrostatically because of the effects of the friction

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of small particles such as dry snow or dust in the vicinity of the transmission lines or even because of the changes that occur in the altitude of the transmission line. The potential difference between the earth and the cloud causes flashes of lightning which take place when the voltage difference between the earth and the clouds reaches 5 to 20 million volts. Another way of explaining this is when the gradient of the potential difference reaches 5000V to 10000 V per cm by both direct and indirect strikes.

Internal over voltages are due to the occurrence of changes, which happen in the conditions of the operation of the power system of the transmission lines. These changes can be either switching over voltages or transient over voltages which happen at high frequencies. These changes occur when the switching operation is in normal operating conditions or when the fault occurs in the network of the transmission lines. If a transmission line is long and unloaded and it is charged, the receiving end voltage is greatly increased due to the Ferranti effect which will result in over voltage in the transmission line system. At the same time if the primary side of the transformers or even the reactors are switched on, the transient over voltage will consequently occur in the system. There are also temporary over voltages and these voltages occur when large loads are removed or disconnected from the long transmission line in both normal and steady state conditions. All these over voltages are emulated in the analyzer by either creating intentional short circuits or by introducing a fault into the system and both approaches have been applied in the simulation. The connections of the emulator for over voltages are shown in figure 8 and the tripping of the emulator is shown in figure 9. The initial readings of the sending and receiving end of the line are shown in figure 10.

EFFECTS OF OVER VOLTAGES ON POWER SYSTEMS

Over voltage can stress the insulation of the equipment in the electrical system and consequently it will damage these insulations especially when this occurs quite often. In addition to this, over voltage which results from voltage surges can result in sparks flashes between the ground and the phase. This occurs at the weakest point in the electrical system during breakdown of gaseous, solid, and liquid insulation and during failures of moving electrical machines and transformers. Electrical power systems suffer quite frequently from abrupt over voltages. These over voltages are caused by abrupt interruption of the heavy loads in the electrical network, impulses of lightening and switching impulses. Even though not all over voltages are strong enough to cause damage to the insulations of the electrical system, any occurrence of over voltages should be avoided in order to make sure that the operation of electrical power system is safe and smooth. Both damaging and nondamaging over voltages in the electrical network should always be prevented by using overvoltage protection relays. The stresses of these over voltages in the power system are usually defined as sudden abrupt surge of voltage to a much higher peak in a very short period. These surges of over voltages are naturally transient which means they occur only for a very short period. In addition to the main reasons for the occurrences of these over voltages in power systems, they could also result from failure of insulation, resonance, arcing ground and switching surges. These over voltages are not usually of very large magnitude and rarely surpasses double the value of the rated voltage. In most cases if an efficient insulation is installed within the different equipment of the electrical power system, this would be more than sufficient to prevent any damage from these types of over voltages. However, over voltages which occur in the power network because of lightning is usually very high and consequently if a proper system of protection is not installed within the electrical power system it is very likely that the damage could be extremely severe. It is for these reasons that most of the devices which are used for over voltage protection are designed for the protection from such surges.

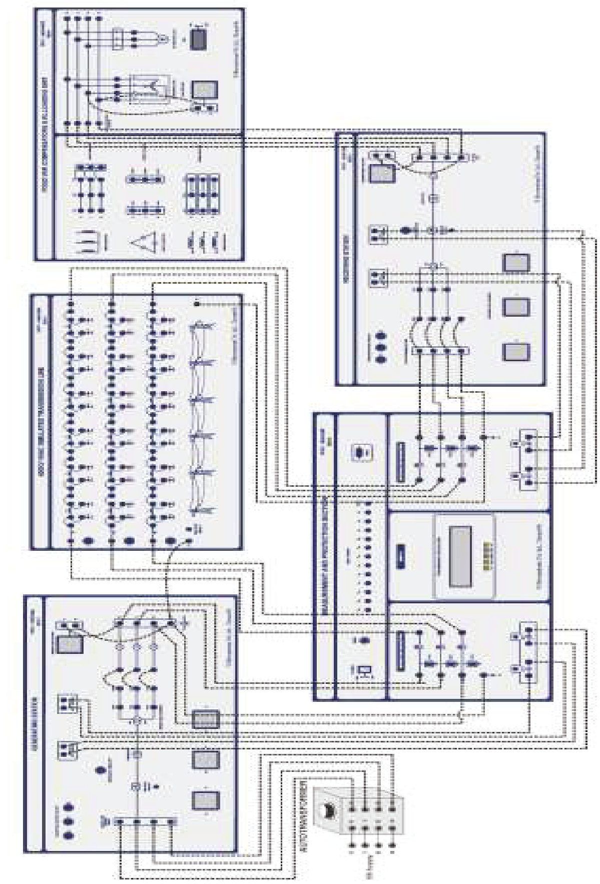

Figure 8. Connections of over voltage relays

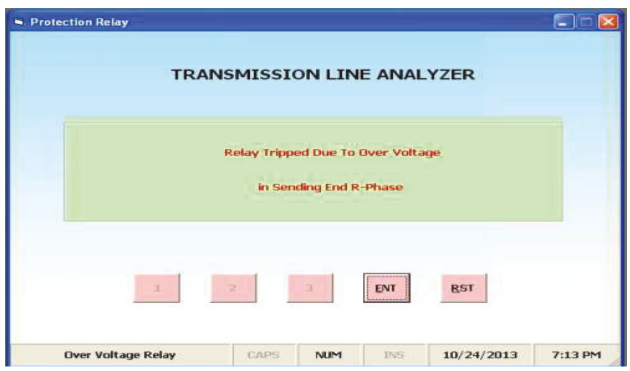

Figure 9. Tripping of overvoltage relay of the emulator

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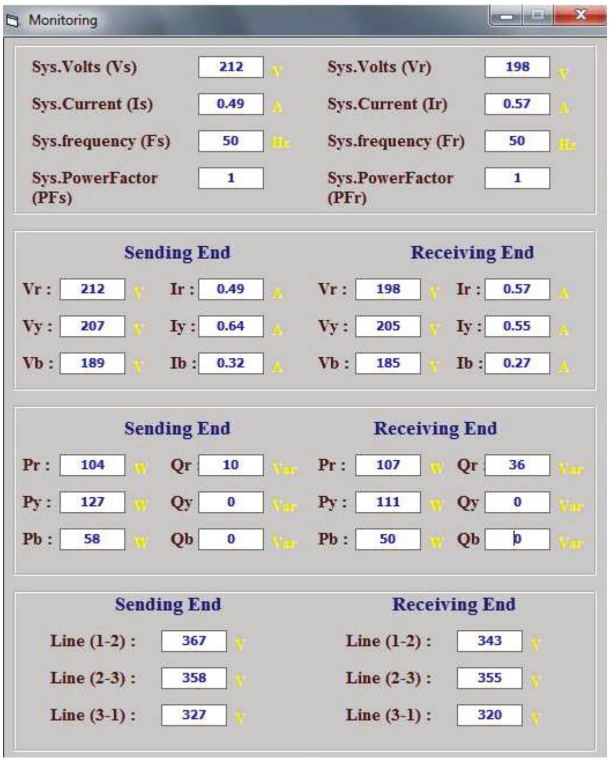

Figure 10. initial readings of the sending and receiving end of the line

3-UNDER VOLTAGE RELAY

The aim of this experiment is to study the operation of under voltage relay using High Voltage Transmission Line Analyzer. An undervoltage occurs when the value of the voltage becomes less than the rated operational value. Undervoltage may result in a malfunction, an error or even or failure of the equipments of the power system. This could also in some cases lead to loss of data if this happens for example in computer systems. Undervoltage can be defined as a sudden drop in the rated voltage which is usually measured in r.m.s. values and it is known as the retained voltage. It can thus be deduced that undervoltage is a reduction of rated voltage in a short period of time and consequently it is mainly caused by short circuits in the electrical power system. Undervoltages can be considered the most common disturbance in power systems and its effect can be quite severe especially in industrial and large commercial sectors such as damages to the sensitivity equipments as well as losses of productions and finances on a daily bases. Examples of the sensitive equipments are Adjustable Speed Drive ASD, Programmable Logic Controller PLC, and chiller control. It is a fact that a detected undervoltage at the the terminal of an equipment could be the result of a short circuit fault which could be hundreds of miles away from the failure point in the transmission lines system. Undervoltages could be caused by many reasons. The main reason is the closing and opening of circuit breakers in the power system. If the circuit breaker of a phase in the power system is suddenly opened, this will cause the line which the circuit breaker is feeding to be disconnected temporarily from the power system and consequently the other feeder lines, which come from the same substation system will appear as an undervoltage. It is also a fact that undervoltage which is caused by a fault can be very critical to the the performance and operation of a power system. It must be stated here that the magnitude of undervoltage can be either equal or unequal in each phase. This will depend on the type of fault that occurred and whether this fault is symmetrical or unsymmetrical. However undervoltages which result from starting of motors are symmetrical. For example induction motors are three phase balanced loads which means that all the high starting current in all the phases are approximately the same. Undervoltages which result from energising transformers result from two main causes. The first cause is the normal operations of the power system such as manual energizing of the transformer. The other cause results from reclosing actions and both of these undervoltages are naturally unsymmetrical. Other undervoltages result from flash overs which occur during a storm in regions close to the coasts and in these areas the transmision lines are usually covered with salt deposits from steams of sea water. These deposits of salt are good conductor of electricity and cosequently faults normally occur in these sitautions. It is a common practise that in urban areas all power lines are burried underground and when digging and foundation work are carried out near these power lines, this ould cause damage to the burried power cables and as a result undervoltages occur. In order to prevent these undervoltages, an underground voltage relay is used which puts the system out of service and consequently no excessive current will pass through and as a result the system equipments are protected from any damage that could be caused by these undervoltages.

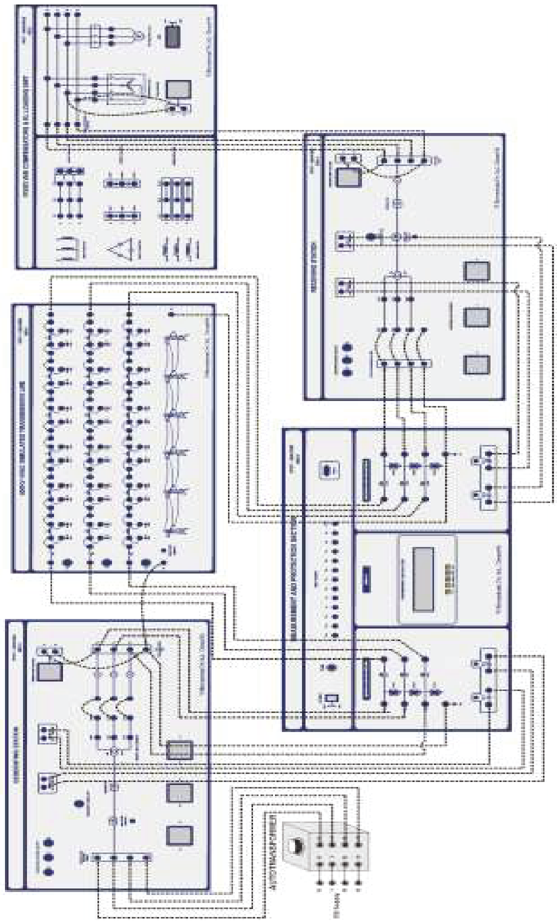

Figure 11. onnections of under voltage relay

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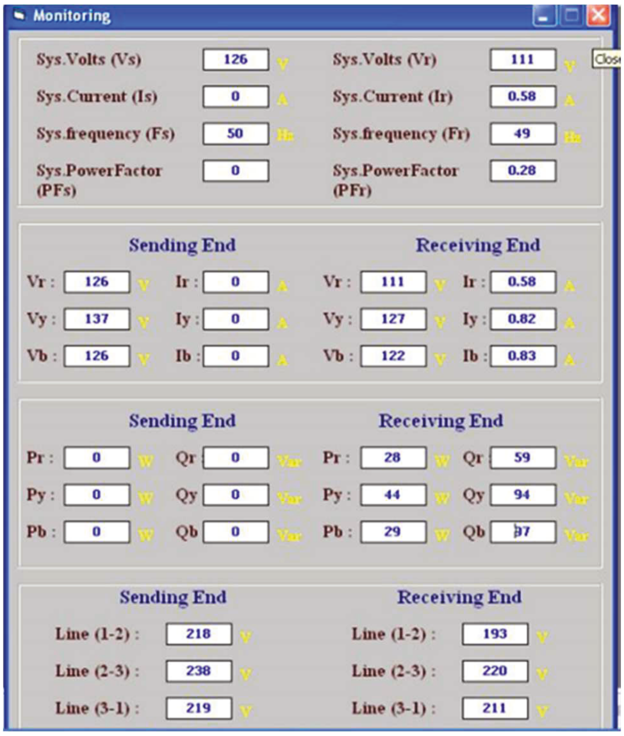

Figure 12. Initial readings of under voltgae relay

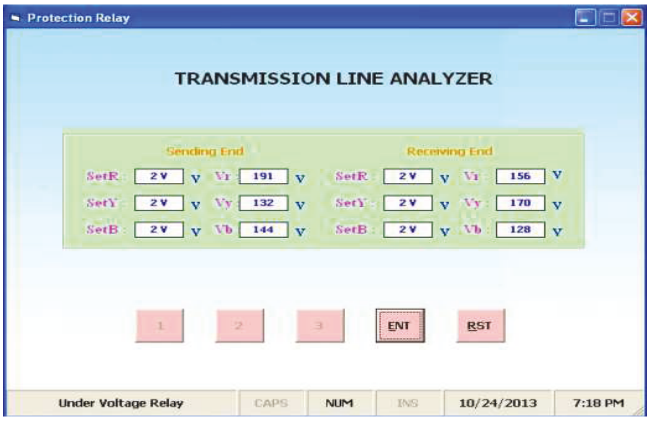

Figure 13. initial readings of under voltage relay

Conclusions

Emualtions of faults and short circuiting of transmission lines were carried out in order to analyse the effects on the performance of HV transmission lines. Three main relays werew investigated namely overvoltgae and undervoltage relays as well as overcurrent relays. It was concluded that it is essential for fault tripping to be in one direction only and when there are many source circuits, it becomes imperative to use directional overcurrent relays. This was used in order to coordinate between all the relays of the system so that a fault can be detected more efficiently. In such systems, the neutral current i.e. the current in the neutral of star-connection power transformer was taken as a directional reference value.

It was evident from the emulations that the spikes of the over voltages occurred in the power system of the transmission line because of the occurrence of changes of the operating conditions of the transmission lines. These changes were both switching over voltages and transient over voltages which happened at high frequencies. These changes happened when the switching operation occurred in normal operating conditions and when a fault occurred in the network of the transmission lines. When a long transmission line was used and it was unloaded and charged, the receiving end voltage has greatly increased due to the Ferranti effect which resulted in an over voltage in the transmission line.

Undervoltages are the most common disturbance in power systems and its effect can be quite severe especially in industrial and large commercial sectors. Undervoltage at the the terminal occurred as a result of a short circuit fault which is introduced at different points of the transmission line. Other reasons were the closing and opening of circuit breakers in the power system. When the circuit breaker of a phase in the power system was suddenly opened, this had caused the line which the circuit breaker is feeding to be disconnected temporarily from the power system and consequently appeared as an undervoltage.

TDOC relays were emulated mainly in radial systems for phase and ground protections. In these situations, they appeared as two-phase relay and one ground relay which protected the line from all phase and ground faults and at the same time minimized the number of relays which were used in the system. However, if a third phase relay was added to the system, it acted as another alternative fault protection.

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