INTERFACING OF POWER SYSTEM SIMULATORS WITH REPRESENTATION OF PROTECTION RELAY SOFTWARE

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Abstract - Modelling and simulation software developed for analysing protecting relaying applications and relay design concepts in energy distribution is described inside the paper. The aim turned into to increase an open device that is simple to use and permits simple destiny expansions. Easy to use presumes that the software program should be appropriate for teaching functions that is accomplished by way of introducing new libraries of sign assets and relay elements evolved in the MATLAB / SIMULINK environment mixed with the SIMULINK / Sim Power Systems, the stated libraries enable an expansion of research aimed toward higher knowledge protective relay design strategies and processes and related programs in power gadget.

Keywords – MATLAB, SIMULINK, Protective relay.

I. INTRODUCTION

Inside the MV networks in Croatia there are 3 methods of substation (transformer) neutral point grounding remedy: isolated, low-ohmic grounded and, from multiple years in the past, resonant grounded. MV distribution networks are especially radially operated. With an purpose to define the criteria for appropriate neutral treatment selection relying on the substation and MV network type, a top level view take a look at has been carried out currently. choice criteria in the have a look at considered: Technical functions of all 3 treatments regarding the earth-fault currents, over voltages and network operation based on literature, measuring, computer evaluation and operation experiences; Human safety necessities and rules (touch voltages), heath and voltage stresses and interferences with telecommunications strains; network importance (number and form of connected clients), length (period of galvanic related traces), kind (cable to overhead lines ratio, kind of poles and sorts of cable junctions and screens); community reliability (SAIFI and SAIDI); Earth systems necessities regarding earth fault currents and soil resistivity. Each criterion has been economically evaluated concerning capital and operation expenditure and then value-benefit analyses were made. The effects of those analyses are criteria for adequate neutral treatment choice regarding mentioned capabilities, requirements and policies.

The examine also emphasized the need for guidelines protection concerning a brand new manner of operation and safety relay requirements as well as harmonization with eu norms. The want for implementation of recent safety methods and primary measuring gadget (contemporary and voltage transformers) coordination have additionally been taken into consideration and analysed. The evaluation done and the results carried out are described in this newsletter. In the scope of the observe, measurements of pre-fault and earth-fault currents and voltages were conducted in 10 kV and 20 kV distribution networks provided from HV/MV substations. Earth-faults have been executed with different fault resistances and types in addition to by way of using distinct neutral factor grounding strategies: isolated, low-ohmic resistive and resonant.
II. TRAITS OF SELECTIVE EARTH-FAULT IN DISTRIBUTION NETWORKS.

Protection strategies for selective detection of earth faults are based on measurements either of permanent or brief currents and voltages upon earth-faults prevalence. A unique property of the isolated and resonant earthed networks is the rise in significance of the measured earth-fault current because of the contribution from healthy feeders, while feeder with the failure has no impact on it. Measurements of to be had currents and voltages within the event of an earth-fault, except these values aren't post processed; imply using directional earth-fault safety. due to repayment in resonant earthed networks, almost about earth-fault modern-day reduction, it's far apparent that shielding system, inclusive of transformers, need to meet very excessive requirements. Maximum techniques work underneath damaging situations of the phase shift among current and voltage (~ninety°). Contrary to the measuring conditions for the duration of quick-circuits, current transformers (CT) are regularly now not tailored to cope with a small earth-fault currents. Adjustment is to be carried out with the aid of the usage of ring-kind (toroidal) transformers. These requirements are even more in meshed than in radial networks because of earth fault currents spreading through branches. most commonly used numerical relays for selective earth-fault detection are:

- Neutral over current relay (50/51N),
- Directional and sensitive directional neutral over current relay (67N(S))
- Watt metric and war metric neutral relays (32P/QN)
- Impartial over current relay based on better (5th) harmonic
- This relay operation is based totally at the fact that inside the resonant networks fifth harmonic is not compensated by Petersen coil. 5th harmonic is generally intentionally delivered upon earth-fault incidence.
- Relay for static or dynamic contrast of impartial currents
  This relays operation is based on evaluation of impartial currents or their changes. impartial currents of various feeders linked at the equal busbar are in comparison.
- Admittance and conductance neutral relays
  This relays operation is based totally on evaluation of impartial admittances/conductance’s modifications.
- Temporary relays
  This relays tracks and compares voltage and currents wave shapes at earth-fault occurrence.

III. RELAY MODELLING

Defensive relays collectively with modern and voltage transformers are a massive a part of the electricity device. Shielding relays rapidly isolate faulted part of the system which permit gadget balance and undisturbed electricity deliver for most customers. Incorrect operation of shielding relays can have adverse outcomes for persisted energy deliver. growing, the use of and teaching protecting relay application and layout ideas assumes multidisciplinary method comprising amongst others electricity system physics, mathematical formulations and digital devices. Majority of components that constitute a modern electrical power system have been effectively modelled for brief research for greater than forty years. The exception is shielding relaying. Development in modelling of electricity relays in temporary analysis seemed inside the closing twenty years. Electrical faults, switching movements and different energy system disturbances, purpose a redistribution of the electric and magnetic electricity stored in capacitive and inductive elements and mechanic energy saved in rotational elements of the network. This redistribution of electrical power cannot occur immediately and the energy machine should undergo thru a transient nation earlier than it reaches a brand new consistent nation. all through the primary few cycles following a energy system fault, high-pace protective relays are anticipated to make a correct
decision as to the presence and region of the fault so that you can preserve device balance and to limit the quantity of equipment damage. The general public of defensive relays make their choices primarily based on essential frequency (50 Hz or 60 Hz) voltage and present day indicators. but, it's far precisely at this second that the voltage and present day signals are badly corrupted by way of fault-triggered transients inside the shape of an exponentially decaying dc factor, and with frequencies above and below the fundamental electricity device frequency. The dynamic performance of protecting relays depends to a huge quantity on their design precept that addresses matters which include selectivity, sensitivity, safety, and dependability. further, the dynamic performance of high-velocity protecting relays depends to a large quantity at the alerts produced by using device transformers, and these signals rely upon the overall brief response of the tool transformers, and the kind of transients generated through the energy machine [1, 2, 3].

Relay software fashions are useful for relay manufacturers, utilities, customers and also for instructional purposes. In widespread, producers use extra sophisticated fashions to guide development and presentation. Representatives of producers can give an explanation for the behaviour of the relays to their clients with the assist of relay models using enter from community simulation applications or from power gadget transient recorders. Depending on the reason they serve it's far viable to create greater or less sophisticated relay fashions. Easy fashions use most effective mathematical equations to explain the select-up and tripping traits of the relays. These models can be used to make well known selections for the selection of relay sorts, and together with network calculation packages they can be used to derive relay settings. Greater sophisticated relay models are a good deal more comprehensive. They method voltage and modern-day temporary waveforms from empty simulations, real fault waveforms captured via numerical relays, or digital fault recorders. This manner user can observe their response to these transients and reaffirm the protection behaviour throughout community disturbances.

IV. RELAY MODELLING IN MATLAB

Matlab has been decided on as programming environment for shielding relaying software modelling for the subsequent reasons: Matlab is well identified as considered one of standard tools for protective relay modelling in enterprise and in university environment [1, 2, 4]. Matlab has effective calculation and visualisation enterprise and permits rapid and efficient software program enlargement without developing any extra programming equipment.

Matlab and its time area solver Simulink create an open and person pleasant device. They provide libraries, fashions and packages allowing integration of different version additives. New models and libraries may be without difficulty delivered.

Simulink and Sim Power Systems allow rapid improvement and closed-loop trying out of safety and manipulate systems used in electricity structures and drives. this is crucial considering actual electricity structures and their safety structures function in a closed-loop way [2, 5]. Sim Power Systems allow modelling of power system additives. It offers computations and analyses much like different electromagnetic temporary applications permitting modelling of the energy structures and its controls inside the same surroundings and as a result, facilitating closed-loop simulation.

The (earth-fault) relays are modelled in order that the overall operating standards of protection structures may be verified. The interaction among network calculation software and software program safety machine models is finished. Closed-loop simulations of relay software fashions with an electromagnetic transient simulation permits assessment of the brief behaviour of the protective relaying algorithms because of modifications and switching within the network. Extraordinary safety settings and their outcomes on the protection behaviour are viable as well as safety coordination evaluation. On this manner the application of relay models can efficiently help the training of students and engineers aim is
to develop relay software program modelling for relevant testing prior the building of a prototype relays. That is critical in the development system because, it lets in testing of diverse relaying algorithms, the relay logic, and to make essential modifications without the want to make changes in hardware or software program modules of the actual tool. Relay algorithm improvement permits use of relay software fashions to test different digital sign processing techniques, safety algorithms, the transient response of digital filters, Phasor estimating techniques, directional or distance detail unit overall performance and evaluation of latest measuring techniques.

Of course, all previously stated cannot completely replace exams with the actual safety devices in real surroundings. Something degree of detail is used in a version, the engineer must be aware of the restrictions of the version. Failure to bear this in mind is a famous weak spot in all layout studies primarily based on models [3].

V. DISTRIBUTION POWER MACHINE MODEL

Within Matlab Simulink environment, Sim Power Systems are decided on as a design tool for modelling and simulating a distribution energy machine. In Simulink surroundings it’s far possible to version and simulate the full system by way of combining Sim Power System with manage machine tools. This lets in optimisation of manage elements of the model. Correct and speedy actual-time simulations are possible via the use of variable step integrator and 0 crossing detection abilities.

The device is modelled consistent with the two actual radial distribution networks wherein earth-fault tests were carried out. Modern and voltage measured records from checks are used for version calibration and additionally as a sign supply for checking out the relay models. Earth-fault and resonant curve subject assessments have been conducted within the substations 110/20 kV Botinec and 110/10 kV Velika Gorica. assessments consisted of earth-faults over exclusive fixed resistances (1÷five Ω, 1, four and 10 okayΩ) and in distinctive conditions (segment wire fell on dry and wet floor, segment twine fell on bushes, brief faults simulated with variable spark gap) at few places within the networks with ungrounded, low-ohmic grounded and resonant grounded impartial points. Earth-faults with resonant grounded neutral factors had been performed with extraordinary tuning of Petersen coils with and without shunt resistor (connected on secondary winding). Resonant curves were additionally measured and recorded. MV networks provided from those substations are ordinarily wide spread semi urban radially operated, with only a few meshed branches. This sort of community became taken into consideration as maximum exciting for resonant grounding method implementation. It's far due to the fact these networks have 8 to twelve feeders on one bus-bar device, with overall sum of 100 to three hundred A capacitive currents, large numbers of short and long supply interruptions and loads of households and small industries linked and with ~21 MVA of common top load.

Modelled distribution network with watt metric relay (crimson container) on feeder 1 is shown in figure 1. Earth-fault is simulated on section A of feeder 1.
VI. RELAY FASHIONS

Erath-fault relays are modelled as typical numerical relays. In Matlab/Simulink surroundings, relays are modelled in the function blocks as it’s far proven in figure 2.

A. Energy Device Version

Energy system is modelled in Simulink surroundings with the aid of use of Sim Power System and different Simulink library elements. Sim Power System is a design tool for modelling and simulating electrical power structures within the Simulink, permitting a electricity gadget model to be constructed in an easy way. It is a effective solution for modelling the electrical strength machine, especially while designing related manage and safety structures. The library incorporates blocks that represent common components and devices located in electric energy networks. The blocks are based on famous electro-magnetic and electro-mechanical equations. The libraries include models of traditional power gadget.

Distribution device is often modelled by not unusual library factors with minor changes wherein important, as an example with arc version. Even though to Matlab is inherent slower power gadget simulation (as compared with EMTP (ATP) [1]), this downside is negligible since the distribution version does no longer gift large gadget.
B. Measuring (Instrument) Transformer Models

Electricity device excessive voltages and currents can't be without delay applied to the relays. Therefore, voltage (VT) and present day (CT) transformers lessen energy system voltages and currents. In Croatia distribution device voltages are generally decreased to the nominal cost of a hundred V and currents are decreased to the nominal cost of 5 A or 1 A. special attention has been paid to the CT modelling concerning the CTs DC saturation impact (observed and recorded in the course of the earth-fault checks with resonant grounding and small fault resistances, determine three) has a super effect in the world-fault safety. With boom of the fault resistance the time steady decreases and the saturation DC element isn't always so effective so the problem becomes much less noticeable. Therefore, it has been endorsed [8] that with resonant grounding ring type contemporary transformers have to be utilized in all bays for earth-fault safety. It’s far anticipated that the ring kind CTs will now not have the saturation hassle as vast as phase CTs. further, a resistance may be introduced in a series with Petersen coil via adding a appropriate resistor or with the aid of growing the copper loses of the coil. With the collection resistance the defined better limit of time consistent may be ensured. Each style of CTs (phase and ring) had been modelled in suitable element.

C. Auxiliary Transformer Fashions

Numerical relays cannot system 100 V of nominal voltage in the course of regular operation and currents of few tens of Amps during faults. The voltages are commonly decreased to inside 5 V to 10 V varieties so that the digital additives are not broken. The voltage discount is executed via the use of both auxiliary VTs and resistance dividers. due to the fact that those devices perform of their linear variety, proportionality elements are used within the relay fashions. Auxiliary CTs are used to reduce the ranges of currents implemented to the relay. The outputs of the auxiliary CTs are handed through precision resistors. Voltage drops across the resistors are used to symbolize currents. If no saturation is expected, modelling the CT and its burden is an easy manner. In popular, the relay input auxiliary CTs can also saturate adding to the complexity of modelling and evaluation. but, saturation of relay enter auxiliary CTs may be left out because: the secondary contemporary is extensively reduced beneath excessive saturation of predominant CTs. furthermore, saturation of the principle CT makes the secondary present day symmetrical doing away with the threat of exposing the relay enter auxiliary CT to decaying DC components. The secondary cutting-edge has a form of short lasting spikes and this boundaries the flux inside the cores of auxiliary CTs. Therefore, auxiliary CTs are not modelled as saturable ones. However, it's far truthful to say that some authors advocate that saturation modelling of auxiliary CTs, consisting of saturation due to low frequency indicators, must be made in the relay fashions.
D. Signal Conditioning

Currents and voltages carried out to numerical relays at some stage in faults contain components of excessive frequencies. Most algorithms of numerical relays are adversely suffering from sign additives of high frequencies. A few high frequency components also are probable to appear to be of the fundamental frequency due to aliasing. Therefore, low pass filters are used in numerical relays. Those filters are analog gadgets. Commonly, a 2nd order clear out is used with a reduce-off frequency about 3 times much less than of the sampling fee. For modelling trendy analog low-bypass filter out, Simulink low-bypass clear out block is used with parameters of method, order and aspect frequency.

E. Sampling and A/D Conversion

Numerical relays convert the analog statistics to numerical form using sampler and analog to digital (A/D) converters. A/D conversion process may be taken into consideration as a -stage manner which include a sampler and a quantizer.

At the primary level sampler creates the sequence s(n) by using sampling the analog signal s(t) at everyday periods of ΔT seconds. This part of the system is usually taken into consideration correct and without any addition of mistakes. the second degree expresses each sample of the sequence s(n) with the aid of a finite quantity of bits giving the sequence squaren). The distinction among the factors of the series squaren) and s (n) is the quantizing noise (it's also called A/D conversion noise). The quantizing method both ought to truncate the signal because it converts the analog information to numerical form or may want to spherical it.

The quantizer degree of a relay version can be skipped for a few cases. Depending on the accuracy requirements of the relay version, the values obtained from the sampler can be without delay used for phasor calculations and for modelling relay algorithm and relay dynamics.

A/D converters have a double effect. Any converter has a confined conversion range in which signals above a sure level are cut off. The conversion variety of the numerical relays is typically in the range of 10 to 50 times. As an example, some relays cut off the inputs at 2 hundred A secondary peaks even as the rated present day is 5 A. The second one issue related to the A/D conversion is a constrained sampling charge. Modern-day relays pattern at quotes as much as 128 samples according to cycle. As closely saturated CTs produces sign pulses of quick length, vicinity of A/D samples on the waveform performs a critical role.

F. Phasor Computing

Electromagnetic temporary evaluation programs calculate voltage and modern waveforms as features of
time. So, it can be necessary to convert the sequences of the values of voltages and currents to their equal phasor as features of time. As an instance, if a transmission line version is used by a numerical relay for detecting line faults, it might now not be vital to convert the sequences to phasor. Alternatively, numerical distance relays that compute apparent impedance should compute phasor. The identical is with the majority of the distribution earth-fault relays.

Phasor computing can be performed with the aid of using one of the several signal-processing strategies. Two commonly used techniques are Discrete Fourier transform (DFT) set of rules and Least squares algorithm. in this venture, phasor are computed with the aid of Simulink widespread DFT detail for instance, over current characteristic calculates modern-day value from unpolished sign samples. System of estimation previous Fourier RMS estimation can include virtual filtering for DC offset elimination. If the best essential frequency (50 Hz) is extracted from waveform via filtering method, this will result in a lower magnitude with heavily distorted waveforms than it's miles case whilst the entire value (true RMS) from complete sign spectrum is extracted.

**G. Relay Algorithm**

In many cases, the modelling of numerical distribution relay algorithm isn't always a complicated process. for example, a ride command of an over current relay must be issued while the contemporary is more than the relay putting. In this situation, the modelling is consisted of assessment of the calculated impedance with the set fee and troubles the experience command if the calculated price is extra than the placing. Similarly, algorithm protection may be realised requiring numerous consecutive checks for ride affirmation.

In some relays, the perfect time delay must be included. For the exact time delays the modelling is a clean technique. The process generally includes the subsequent steps:

1. Begin a timer while a experience command is indicated.
2. Take a look at the trip standards after the following iteration is finished via the analysis program.
3. Increment the timer if the experience criterion is satisfied.
4. If the trip criteria are not happy, both decrement the timer or reset it. The decision ought to be based on what the relay being modelled is designed to do.
5. Test if the favoured time postpone has elapsed or not.
6. If it has, model the tripping of the correct circuit breakers. Otherwise, revert to step 2.

The modelling of inverse-time delays, which includes in inverse-time over current relays, is quite greater complex. In discern four an earth-fault over current definite time (51N) relay version is proven. Version consists of: enter circuit comprising auxiliary CT and analog filter A/D converter with digital clear out Discrete Fourier transformation module and Comparator with time delay factor.

In determine five output of this relay through additives is shown. The picture indicates from up to backside respectively: three phase contemporary waveforms, 3I0 earth-fault waveform, earth-fault waveform after filtering, earth-fault modern RMS of base harmonic (50 Hz) and relay module pick out-up and journey signals.
VII. RELAY LIBRARIES

As shown in figure 6, several fashions of earth-fault relays are modelled and stored in relay library. Modelled earth-fault relays are: over current (51N), directional voltage or contemporary polarised directional (67N, 32U or 32I), directional touchy or watt metric/war metric (67Ns, 32W) and admittance earth-fault relay. Specific time earth-fault over current relay is non-directional relay which compares measured or from phase currents derived earth-fault modern with set consistent cost.

Inputs for classic directional contemporary polarised relay are 3I0 and Ipol, wherein Ipol is polarising modern acquired from impartial point floor conductor [6]. So, this relay is only appropriate for solidly or low impedance grounded distribution networks. It calculates torque (term derived from electro-mechanical relaying) based totally on magnitudes and relative attitude of analog enter quantities, Equation 1. Relay compares the result of calculated torque against set thresholds. If torque is nice and above the wonderful threshold, then relay determines a ahead earth-fault. If torque is terrible and beneath the terrible threshold, then relay determines a opposite fault.

\[ T = |I_{po|} \cdot 3I_0 \cdot \cos(\phi_{po|} - \phi_{3I0}) \]  
(1)

Directional voltage polarised relay makes directional choice in line with Equation 2. The relay compares
calculated $Z_0$ towards $Z_{0F}$ and $Z_{0R}$ thresholds to decide the direction of the earth fault.

$$Z_0 = \frac{Re\{3V_0e^{(-j\theta_0)}-3I_0e^{(j\theta_0)}\}}{j\omega \delta t^2}$$

where $e^{-j\theta} = \text{complex conjugate}$:

$3V_0 = V_A + jV_B + V_C$

$3I_0 = I_A + jI_B + I_C$

$\theta_0$: Line zero-sequence impedance angle

Directional watt metric relay makes directional decision in keeping with Equation 3. The relay compares calculated $W$ towards $-w$ and $+w$ thresholds to decide the course of the floor fault. $W < -w$ indicates a forward fault and $W > +w$ shows a reverse fault.

$$W = Re\left[\overline{V_0} \cdot \overline{I_0}^*\right] = V_0 I_0 \cos \varphi_0$$

Earth-fault admittance relay algorithm is centralised and it simultaneously uses zero currents from all galvanic linked feeders (on the identical busbar) and not unusual 0 voltage. It calculates zero asymmetry admittance for every feeder. Asymmetries arise attributable to asymmetries of feeder capacitances to the earth or of an earth-fault. Gain is that it also calculates asymmetry admittance trade $dY$. This set of rules has two thresholds, an absolute $Y_{as_{\text{max}}}$ and the sensitive one $dY_{as_{\text{max}}}$.

VIII. CONCLUSION

In this paper method for strength system and relay modelling is described according to the applicable literature. A distribution system and several earth-faults relay models are evolved using person friendly open device surroundings Mat lab and Simulink. Evolved complete relay fashions procedure voltage and modern-day temporary waveforms acquired from electromagnetic transients simulations, real fault waveforms captured via numerical relays, or from digital fault recorders. This way consumer can have a look at their response to those transients and reaffirm the safety behaviour for the duration of network disturbances inside the destiny purpose is to broaden relay software program modelling for relevant trying out earlier the constructing of a prototype relays that is vital inside the improvement manner because, it allows testing of various relaying algorithms, the relay common sense and to make necessary changes without the want to make adjustments in hardware or software program modules of the actual tool.

REFERENCES
