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Development of a Virtual Relay Model (VRM) of a Microprocessor Based Sub Harmonic Protection Relay

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SUMMARY

Worldwide, expeditious installation of renewable and distributed energy resources is occurring now. To achieve quicker execution of these projects, most of the existing transmission systems are being upgraded with the addition of various compensating devices such as SVCs, series capacitors, shunt compensators to support wind farms, large PV systems, and other distributed energy resources. In this context, the operation of the power grid due to the additional energy resources is posing new challenges in the field of power system protection, monitoring, and control. Many events have occurred in the existing installations with Wind Turbine Controller interactions due to Sub Harmonics generated in series compensated systems [1-4]. In order to meticulously study these controller interactions for all possible contingencies, a detailed modelling of power systems protection relays in electromagnetic type (EMT) simulation programs is essential. Majority of the power system utilities and planners use the COMTRADE file playback of the simulated and / or the recorded data into the microprocessor based Relays through the real time digital test systems to accomplish the protection coordination. This is a time consuming, expensive and laborious process. This paper presents a novel Virtual Relay Model (VRM) to interface with electromagnetic type simulation programs, such as PSCAD, to economically, flexibly, and reliably carry out the complex interactions of the power systems with various renewable energy resources.

KEYWORDS

Power system protection, protection relaying, power system simulation, testing and verification

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INTRODUCTION

With ever increasing complexity of power systems, advanced microprocessor based protection relay's protection complexity is also increasing. In order to cope up with the complex interactions of the renewable energy resources, a detailed simulation based testing of protection relays is essential. Even though the available power system simulation environment provides basic protection relay models, it is not sufficient to study certain new events reported [1-4] with such basic relay models. Presently, the system studies are carried out with a simple or partial-relay-logic model, which differs significantly from that of the microprocessor based commercially available relay. Also, testing microprocessor based relay with selected COMTRADE waveforms created from the simulation and playing back via a real time playback unit is an inefficient and time consuming. If a detailed relay model is available to the simulation environment, more rigorous simulation studies can be carried out to increase the security and reliability of the power systems for various contingencies with end-to-end and closed loop simulations.

This research investigates the development of a detailed virtual relay model (VRM) of an actual microprocessor based relay that can be effectively used in simulation studies.

DEVELOPMENT OF VIRTUAL RELAY MODEL (VRM)

The primary objective of this effort is to develop a simulation model (VRM) of the actual microprocessor based protection relay that will be effectively used in the simulation environment, such as PSCAD. Therefore it is essential to understand the interfacing of actual protection relays with the power system. Figure-1 shows the typical arrangement of an actual hardware relay in a simple power system. Typical relay takes voltage & current as analog inputs, breaker status & digital outputs from other devices as digital inputs and virtual signals (e.g. IEC 61850 GOOSE) from other devices as virtual inputs. In addition, user interface program provides the interfacing for setting down loading/up loading, metering, recording, automation, etc.. Relay firmware includes A/D conversion process, digital signal processor (DSP), real time operating system (RTOS), time synchronizer, etc..

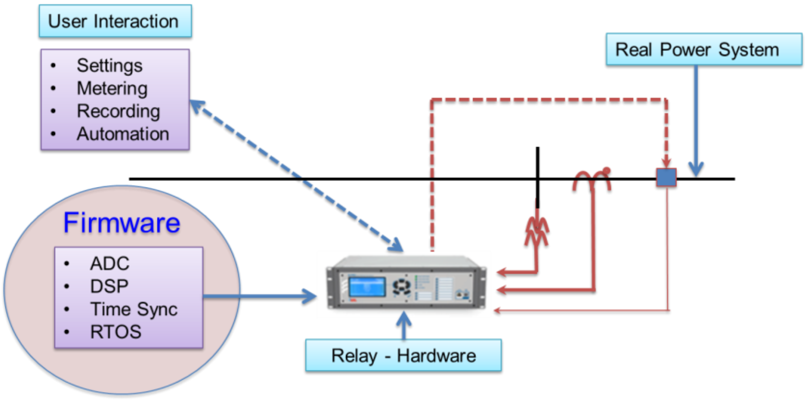

Figure 1: Typical arrange of an actual protection relay

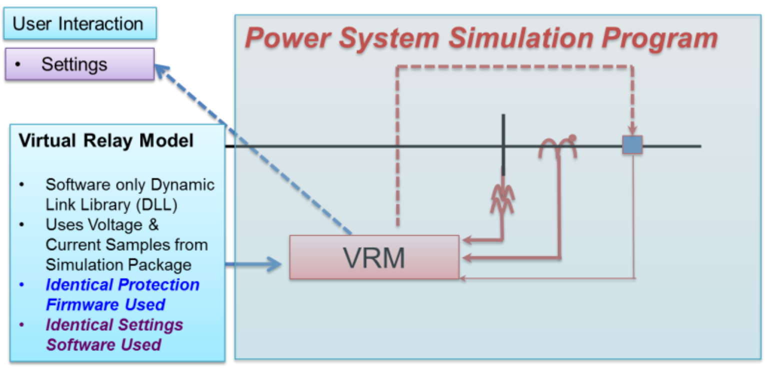

Figure 2: Replication of VRM

In developing the VRM for power system simulation programs, priority has been given to provide the basic input & output interfacing between the relay and rest of the aforementioned power system components and user interaction for the settings. Figure 2 shows the basic components in the VRM, which has been designed in such a way that the same setting file used in the actual microprocessor based relay can be used without any modification. This allows user to (a) fine-tune the settings in the simulation program and upload the same into the microprocessor based relay and (b) download the setting from the relay and use the same in the VRM simulation for further analysis.

In order to achieve the above requirements, a dynamic link library (dll) based implementation has been proposed as shown in Figure 3. The relay-dll includes the DSP calculations whereas; setting-dll provides the setting interfacing for relay-dll. The communication interface provides the interfacing for settings and communication between relay-dll and setting-dll. It is important to note that all the libraries created as stated above uses the identical code used in the microprocessor based hardware relay as shown in Figure 2.

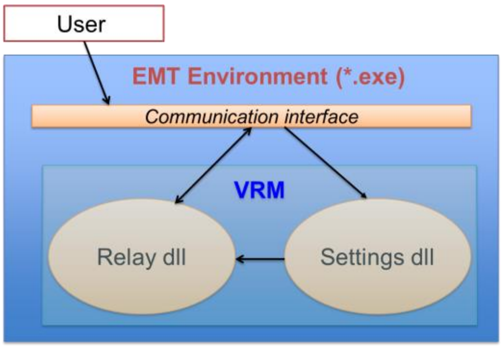

Figure 3: Integration in EMT simulation environment

Basic framework for integration with the EMT simulation programs was developed and as an example case PSCAD simulation program was used for demonstration. Figure 4 shows the simulation model and its setting configuration developed in PSCAD. I1 to I4 are three phase current inputs whereas V1 & V2 are three phase voltage inputs. EI and VI denote external inputs and virtual inputs respectively. Internal logics, alarms, trips and outputs are provided as outputs. All the above inputs and outputs are multi-dimensional arrays depending on their actual size (or length). The configuration provides the link for interfacing the settings for the relay.

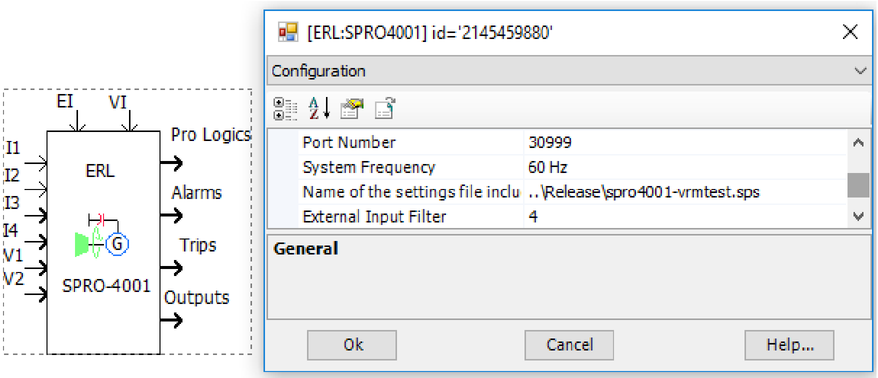

Figure 4: EMT simulation model and setting configuration in PSCAD

SIMULATION AND MODEL VALIDATION

Validation of the simulation model for accuracy is essential to ensure that the VRM behaves close to the actual hardware unit. In order to validate the operation of the relays COMTRADE files captured during actual sub synchronous resonance conditions were played back into the hardware unit of the sub-harmonic protection relay [4] using a real time playback system [5] as shown in Figure 5.

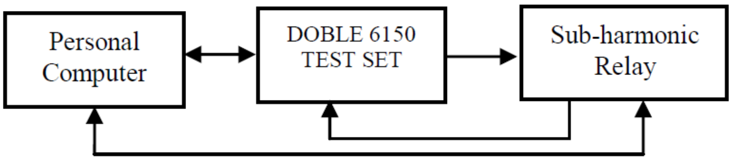

Figure 5: Test setup for actual relay

The same waveforms were tested with the simulation model of the sub-harmonic relay developed in PSCAD/EMTDC using the same setting files. Two different fault scenarios are considered, as described below.

Scenario-I

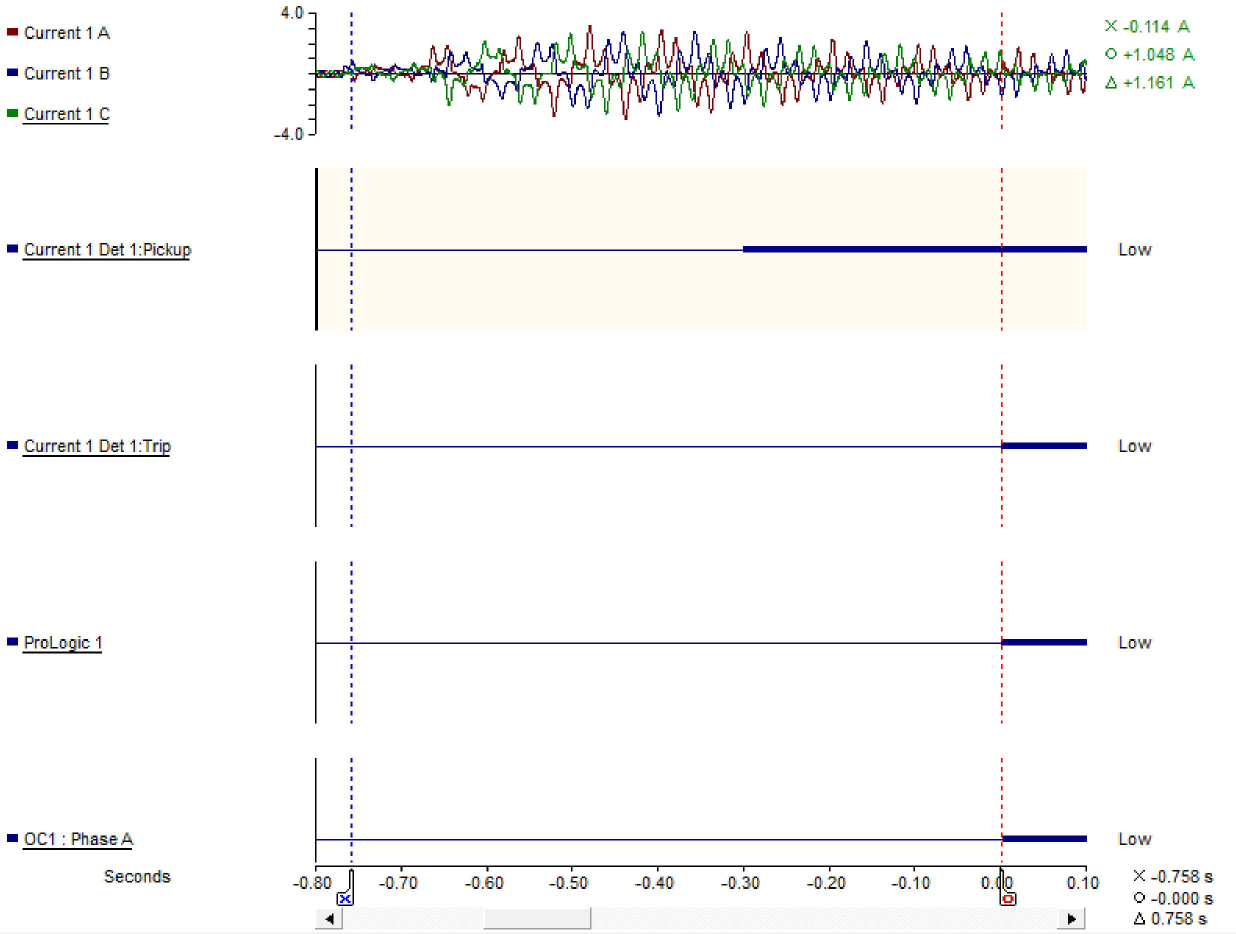

Figure 6: Operation of the actual relay for scenario-I

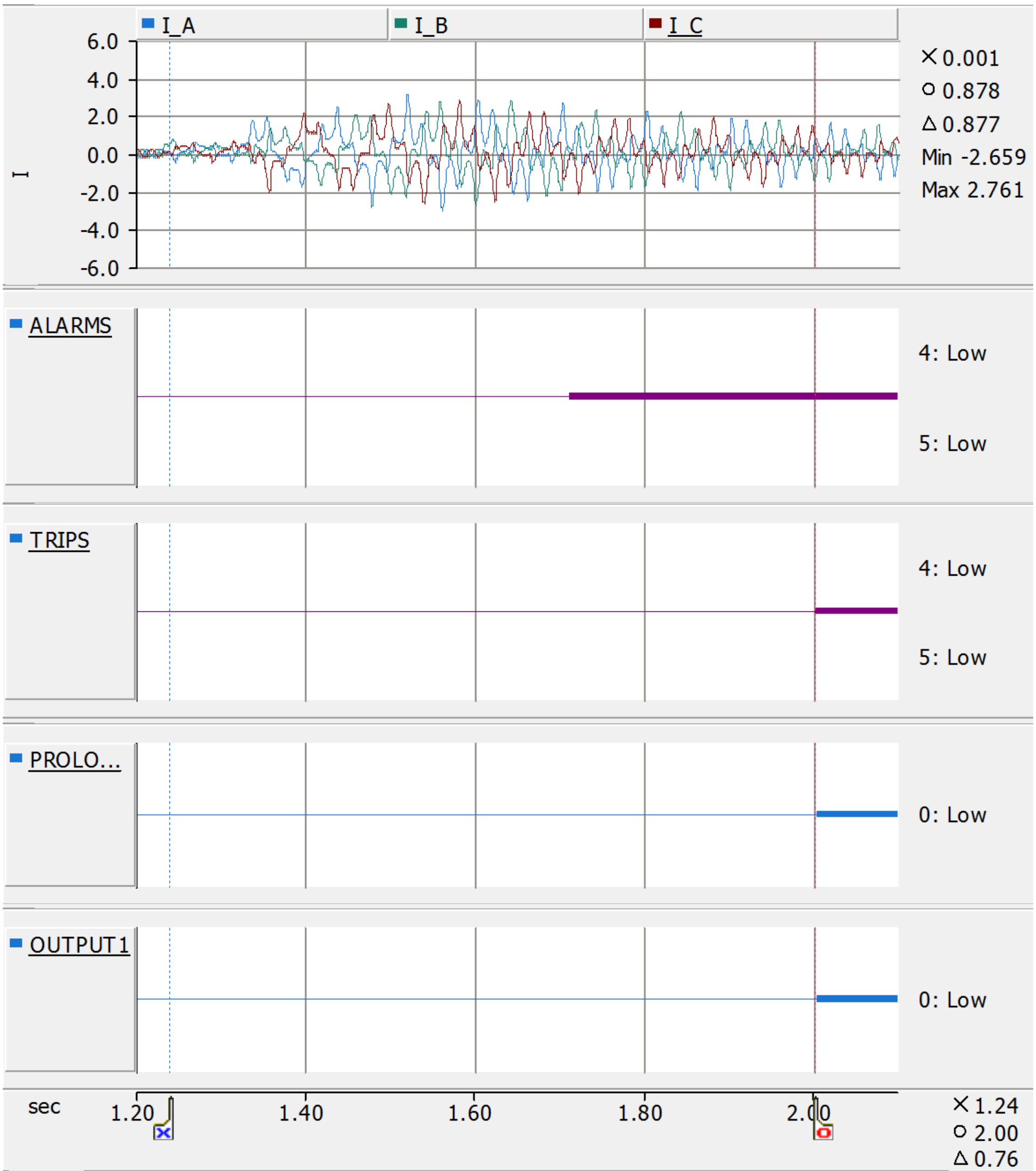

Figure 7: Operation of the VRM for scenario-I

In this scenario, current waveforms recorded during an actual sub-synchronous resonance event reported for a type-3 wind farm connected to a series compensated transmission line in Xcel Energy was used. Figure 6 shows the operation of the actual relay. For the given setting file, operating time of 0.758s was observed. Behaviour of the virtual relay model for the same disturbance and same setting file is shown in Figure 7. As it can be seen from the results, operating time of the simulation was reported as 0.76s.

It should be noted that a generic setting file is used for comparison purpose and appropriate setting shall be used for optimal operation.

Scenario-II

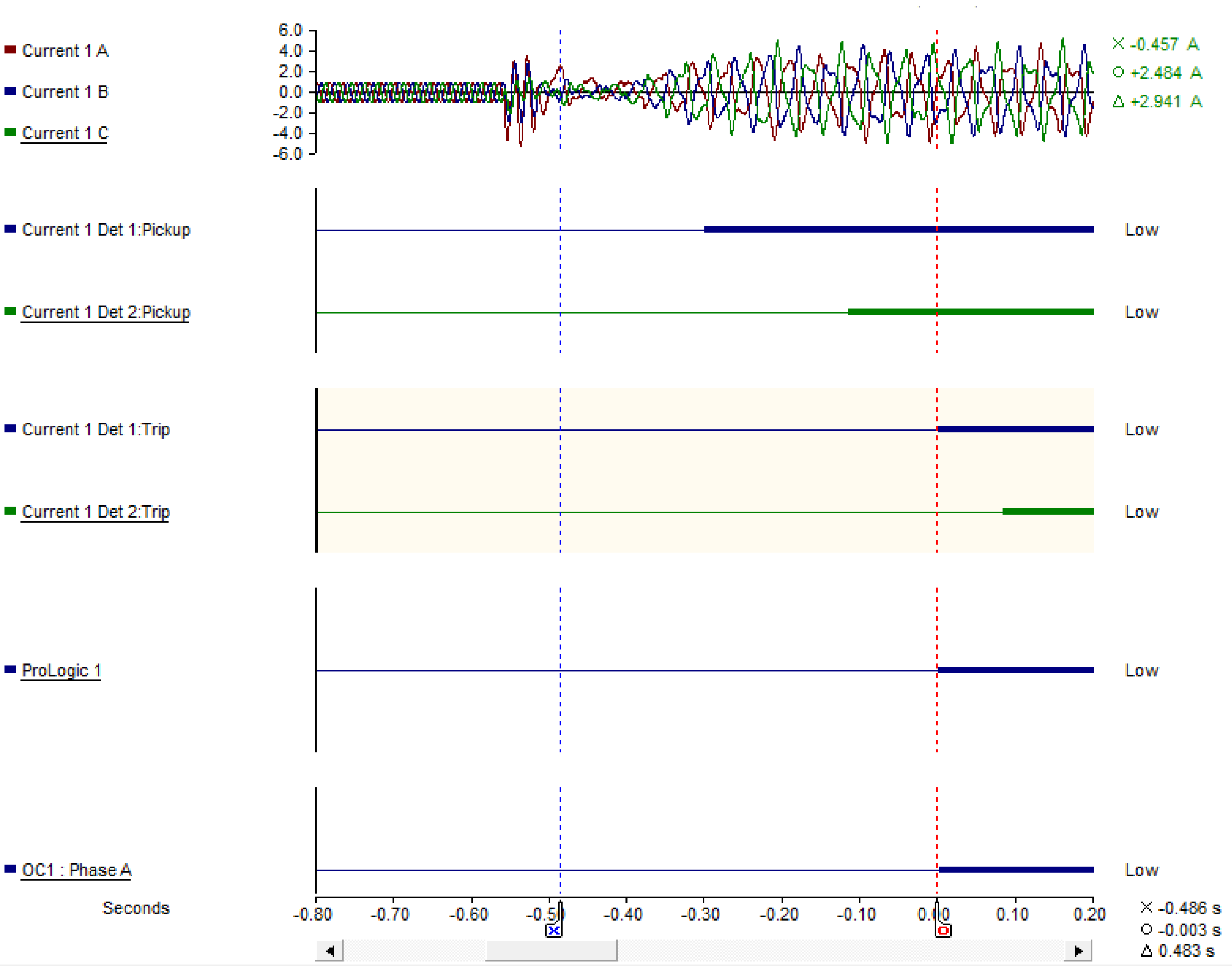

Figure 8: Operation of the actual relay for scenario-II

In this scenario, the recorded waveforms observed during another sub-synchronous resonance event reported for a type-3 wind farm connected to a series compensated transmission line in Texas was played back into the actual relay. Figure 8 shows the operation of the relay during this event. As it can be observed from Figure 8, response time of the relay is 0.483s. The same disturbance was tested using the virtual relay model. Figure 9 shows the behaviour of the PSCAD/EMTDC simulation model. In the simulation model, response time is reported as 0.48s. It should also be noted that the same setting file used in scenario-I is used in this scenario and appropriate setting shall be used for optimal operating speed.

In order to ensure accurate operation of the VRM, behaviours of the actual relay and virtual relay were compared for all protection functions (including backup protection functions) under various conditions covering all boundary conditions. Accuracy limits observed during the PSCAD/EMTDC simulations stayed well within the accuracy limits of the actual simulation model. Due to space limitations, these results are not shown in this paper.

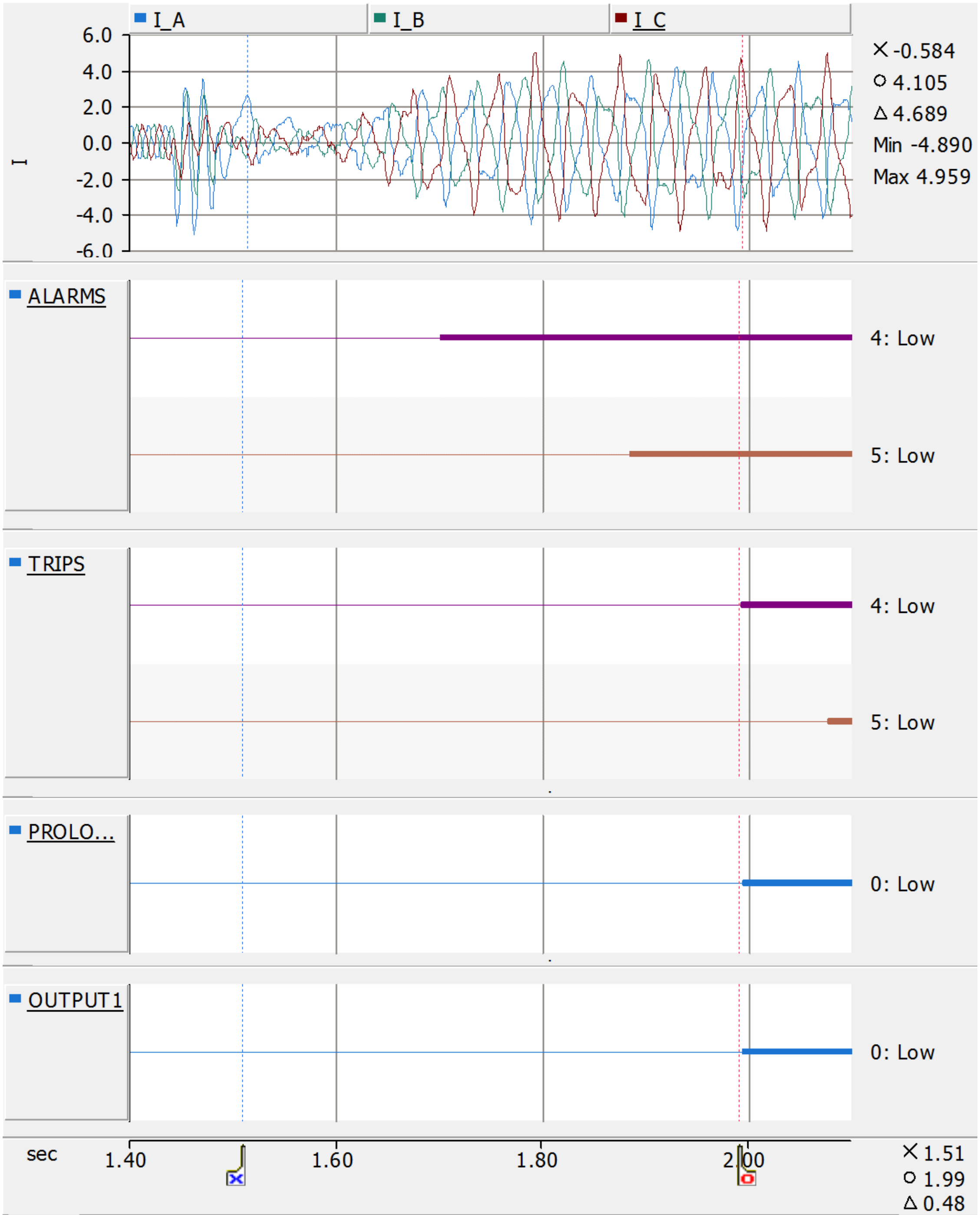

Figure 9: Operation of the VRM for scenario-II

CONCLUSIONS AND FUTURE WORK

In this research, development of a VRM of an actual microprocessor based relay was investigated. Basic framework for interfacing the simulation model of the actual relay in EMT simulations was developed. In this study, commercially available sub-harmonic protection relay was selected and implemented in PSCAD/EMTDC environment. Performance of the VRM was verified and compared with the actual relay using several test scenarios. Result obtained so far showed accurate operations well within the limits defined in the actual relay. Further research is being carried out to improve the features in the simulation model and develop the VRMs for other relay types such as multifunctional distance protection, transformer protection, and bus protection relays.

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