

Modelling of Voltage Regulation Issues in SWER Systems Using PSCAD/EMTDC

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ABSTRACT

An economic (low-cost) distribution system, called Single Wire Earth Return (SWER), has been used extensively in remote parts of Queensland and other states of Australia to deliver electrical energy to small customer loads, scattered sparsely over vast areas. Ergon Energy Corporation, a distribution utility in Queensland, has identified voltage regulation as one of the key issues being faced in this area, as loads continue to grow in rural distribution networks. In order to study voltage regulation issues of these systems, suitable models must be developed.

Commercial software packages which are currently used by Ergon Energy, such as DINIS and PSS Adept do not offer all features required for modelling the SWER distribution systems in complete detail. Therefore, custom modelling using more flexible software tools available is deemed necessary. One such a software tool is PSCAD/EMTDC (PSCAD) developed by the Manitoba HVDC Research Centre in Canada. This is a commercial software package based on similar algorithms to most common electromagnetic transient programs such as EMTP or ATP.

In this paper, modelling of SWER systems using PSCAD is discussed. Building blocks for the models of the distribution system components are developed. The effectiveness of this modelling approach is demonstrated using case studies of a real SWER distribution system. By using these models, the voltage regulation problem and the suitability of the proposed voltage control methods can be studied for a large network.

This paper is introductory material for the paper "Reactor Solutions for Voltage Control of SWER systems" also being presented at AUPEC 2006.

1. INTRODUCTION

Rural electrification in Australia is characterised by very long three phase and single wire earth return (SWER) distribution feeders and small sparsely scattered loads. Individual loads are typically less than 100 kW with most falling into the 2 kW to 15 kW range. Distances between customers can range from less than 1 km up to 25 km [1].

A typical 22 kV distribution system in a rural area might consist of a very long single 22 kV three phase main backbone feeder of over 100 km length. This feeder

would supply three phase and single phase loads along its length with various two and three phase spur feeders required to reach customer loads away from the main feeder.

In areas where customer load density is very low and distances between customers are high, 12.7 kV or 19.1 kV SWER feeders would be used. A SWER feeder is a unique distribution line that consists of a single conductor energised at high voltage. Typically SWER feeders are 12.7 kV or 19.1 kV in Australia. A SWER feeder uses the earth as a return path for load currents, rather than a dedicated neutral or earth conductor. This makes it incredibly simple and economic to construct and it has various reliability advantages due to the small number of components. There are over 150,000 km of SWER feeders currently in use in Australia [2].

A 22/12.7 kV or 22/19.1 kV isolating transformer is used to connect two phases of a 22 kV feeder to a SWER feeder. This transformer prevents earth return currents from interacting with the 22 kV feeder, whose earthed neutral could be over 100 km away; thus providing a local earth return point for currents flowing in the SWER feeder. Uncontrolled earth return currents can create safety hazards from step and touch voltages and can interfere with telecommunications circuits by introducing noise from induced voltages. Figure 1 shows a detailed schematic of a SWER feeder connection and associated customer load connections.

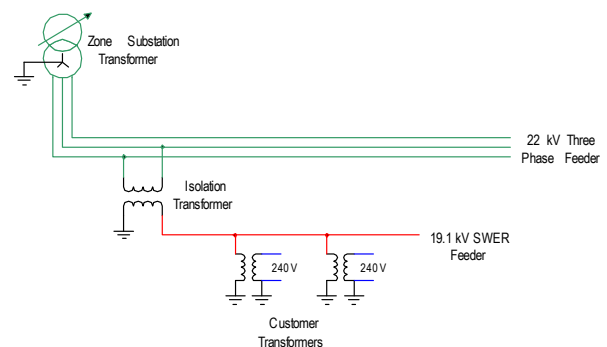


Figure 1 – SWER feeder schematic

Feeder impedances of both the three phase and SWER feeders are high due to the nature of the construction. Because the loads were typically very low when these systems were built, extensive use was made of small gauge ACSR (aluminium conductor, steel reinforced) and steel conductors. The ACSR conductor is used for the three phase feeder backbone and for some sections of the larger SWER feeder backbones. Three phase spur feeders and the majority of the SWER feeders are

constructed using three strand steel conductors. These feeders exhibit relatively normal feeder reactances, but very high feeder resistance.

Due to recent strong electrical load growth in Queensland, rural distribution systems that were designed with a certain load limit, are now operating beyond their original specifications. In the past 30 years, the standard SWER connection transformer size has risen from 5 kVA or 10 kVA to 25 kVA [3] [4]. One of the big factors in Queensland's recent load growth has been the lowering cost of air conditioning. In the past few years, the market has been flooded with low cost air conditioning units, making household air conditioning common rather than a luxury. This is putting high demands on both rural and urban distribution systems.

Another important consideration is the revenue earned from SWER systems. Low customer and load density results in very low revenues being earned. This makes justification of expensive upgrades very difficult on an economic basis alone.

One of the key issues pertaining to SWER feeders is that of voltage regulation. Capacity limitations are occurring due to voltage regulation issues. During very light load periods the SWER line capacitance creates voltage rise issues toward the end of the feeder due to the Ferranti effect. To combat this issue, fixed shunt reactors are used control voltages. Unfortunately these reactors add to the load during peak load periods. As a result, excessive voltage drop limits the load capacity of the feeder.

Various new strategies have been identified as potential solutions to these voltage regulation issues [5]. However each needs to be modeled in detail to assess its worth. This requires models of each SWER feeder component to be developed in software.

2. SOFTWARE SELECTION

There are various load flow software packages available, which enable the steady state analysis of single phase feeder systems. Ergon Energy Corporation and Connell Wagner Pty Ltd (both involved with this project) use software packages such as PSS Adept, DINIS and EDSA. However these packages have some limitations with the type of analysis that is required. For this project, in addition to calculating steady state voltages, currents and power flows, the software needs to be capable of modelling:

- Transformer and reactor inrush and saturation
- Switching transients
- Power electronic components
- Control systems
- Dynamic load that changes with time

The software needs to provide time domain analysis of waveforms to enable further study of voltage flicker and harmonic issues arising from various voltage regulator technologies being studied.

The software selected for this project is PSCAD/EMTDC (called PSCAD for convenience) developed by the Manitoba HVDC Research Centre in Canada. It provides the required functionality and has a very powerful user interface to enable quick building of models and excellent output capabilities for displaying data.

PSCAD was initially developed by Manitoba Hydro to enable analysis of large scale HVDC systems that were developed in the Manitoba region in the 1980's and it has since gone on to become one of the very popular and well respected electromagnetic transient programs available today. It uses similar algorithms and processes to other transient programs such as EMTP and ATP.

3. SWER SYSTEM MODELS REQUIRED

3.1. COMPONENTS AVAILABLE IN PSCAD

PSCAD already has a very comprehensive library of models and components available. Components of relevance to this project include:

- Three phase and single phase a.c. sources
- Single phase transformer models with saturation capability
- Lumped R, L and C components for modelling loads
- A huge array of control system components

3.2. NEW SWER FEEDER COMPONENT CREATED IN PSCAD

One component that does not exist in PSCAD is that of a single wire earth return feeder. Three phase coupled or nominal π components exist, but there is nothing specifically single phase. A SWER PI circuit can easily be constructed using lumped RLC components, however this is very time consuming when modelling large SWER systems where there can be up to 100 line segments in each feeder.

Before a model can be created, line parameter calculation theory applicable to SWER feeders needs to be explored. The resistance of the earth return path and inductive reactance of the SWER feeder circuit is calculated using simplifications of Carson's equations [6]:

$$R_e = 0.0009875 \cdot f \text{ Ohms/km}$$

$$X_o = j0.0028925 \cdot f \cdot \text{Log}_{10} \frac{\text{GMD}}{\text{GMR}} \text{ Ohms/km}$$

where: GMR = Conductor geometric mean radius (m)

ρ = Soil resistivity (ohm.m)

f = Frequency (Hz)

$$\text{GMD} = 658 \cdot \sqrt{\frac{\rho}{f}} \text{ (m)}$$

This shows that regardless of soil resistivity the earth return path is approximately 0.05 ohms/km for a 50 Hz network. This demonstrates the earth's low resistance to earth return currents. The total resistance of a SWER feeder circuit is then sum of the conductor resistance and the earth return path resistance.

A specific SWER feeder π circuit component was created using the PSCAD component builder. The component was created using a graphical symbol with two electrical connections (A1 and A2) as shown in Figure 2. A ground connection (G) was provided internal to the component. Input data is provided to the component using an input menu system as shown in Figure 3. Internal to the model, Fortran code is written to specify the connection of the RLC components between the three electrical connections as shown in the screen shot of Figure 4. Some pre-processing of user data is required and this is shown in the screen shot of Figure 5. PSCAD's inductance units are in henries, so some Fortran code is required to convert the inductive reactance to inductance, based on the frequency entered by the user. Also some code is used to halve the capacitance before it is placed at each end of the feeder model.

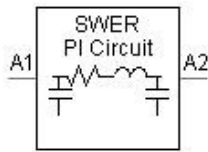


Figure 2 – New component graphic

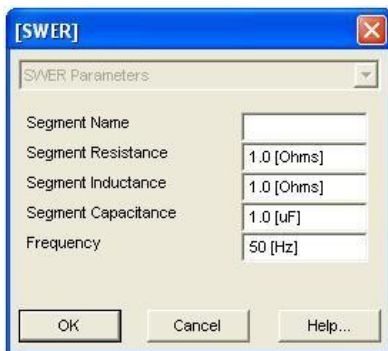


Figure 3 – User data entry menu

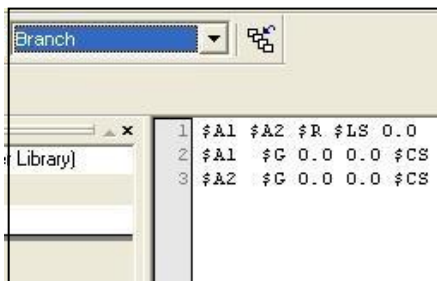


Figure 4 – Fortan code specifying connectivity

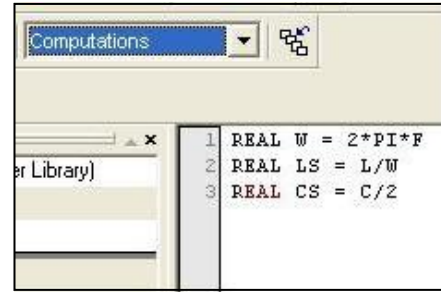


Figure 5 – Fortran code to pre-process user entered data

4. JERICHO NORTH SWER FEEDER CASE

One of the SWER feeders in the Ergon Energy network that is being used as a case study is the Jericho North feeder. This is a 19.1 kV SWER feeder near the township of Jericho in Central Queensland. This is a very large SWER feeder with 415 km of total feeder length. There are 52 customer loads drawing a total peak load of 185 kVA at nominal voltage. The feeder is constructed from a mix of "Raisin" ACSR (for the main backbone) and 3/2.75 mm SC/GZ conductor (for spurs).

The case file has been built up using the following components:

- 22 kV three phase source to model the 22 kV system as shown in Figure 6
- 22/19.1 kV single phase transformer to model the isolation transformer as shown in Figure 6
- 86 SWER PI circuit segments to model the SWER feeder (using the new component)
- 52 series lump RL components to model customer loads
- 8 series lumped RL components to model the fixed shunt reactors connected to the SWER feeder

The complete model is shown in Figure 15 at the end of this paper (the model is very large).

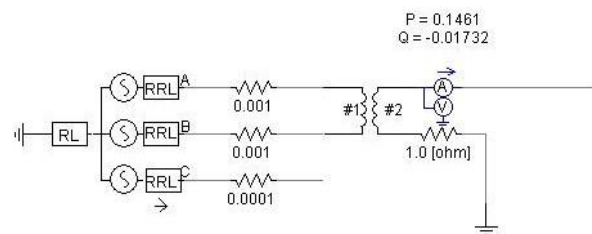


Figure 6 – 22 kV three phase source and SWER isolation transformer with metering connected to outgoing 19.1 kV SWER feeder

4.1. LOAD MODELLING

For this project, the loads have been modelled as constant impedance loads. That is, the load (ie the power consumed) varies with voltage. This is indicative

of heating, cooking and lighting loads common of domestic consumers but does not model the constant power loads such as induction motors with great accuracy. However, the constant impedance load assumption is considered satisfactory for the purpose of this model which is to investigate potential new voltage regulator applications.

To enable the load to be varied in real time, variable R and L components have been used with external control signals used to set the resistance and inductance values. Figure 7 shows the standard load model that has been created.

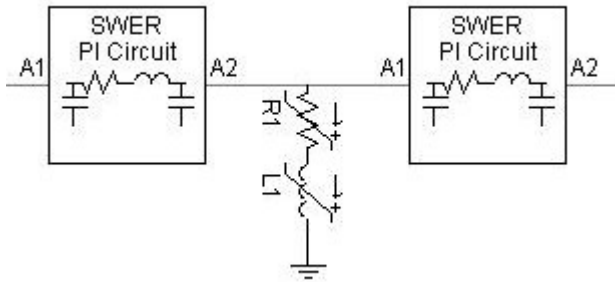


Figure 7 – Variable load model

Several PSCAD control components have been used to enable the load to be set at any preset value between 30% and 200% of the existing peak feeder load. In addition to this an option allowing the load to automatically ramp between any two load values over a set time period has been created using the PSCAD control components.

4.2. SHUNT REACTOR MODELLING

The fixed shunt reactors have been initially modelled using a lumped inductance and a resistance to give a Q factor of 50 at 50 Hz. The reactors have been connected to the SWER feeder using a single phase circuit breaker component as shown in Figure 8. The circuit breakers are all controlled from a single PSCAD switch control panel to enable the reactors to be switched on or off. Whilst this is not how they are operated in the real system, this enables the study of voltage regulation with and without the reactors in service.

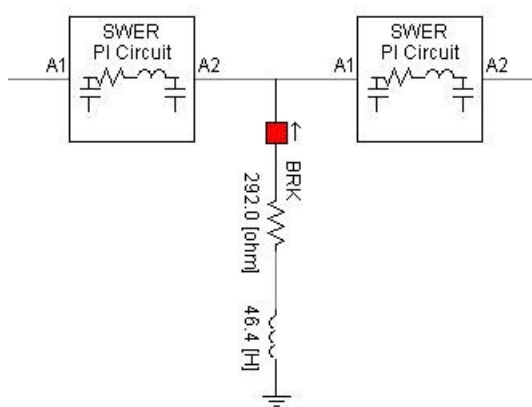


Figure 8 - Reactor model and control panel

5. USE OF THE COMPLETED MODEL

Several runs have been completed for illustrative purposes and the outputs from the model are shown in Figures 9 to 14. For all cases the 22 kV source is fixed so that all voltage regulation is confined to the SWER feeder system itself. The load is initially 100% of the known peak load and is automatically ramped from 100% down to 30% of peak load between 0.5 and 1.5 seconds. There is an initialisation period of 0.1 seconds.

The SWER feeder voltages are measured at various points in the feeder network. SWERV100 is the voltage measuring node at the isolation transformer. SWERV128, SWERV146 and SWERV173 are voltage measuring nodes at three points near the extreme ends of the feeder.

Current, active power and reactive power are measured at the isolation transformer.

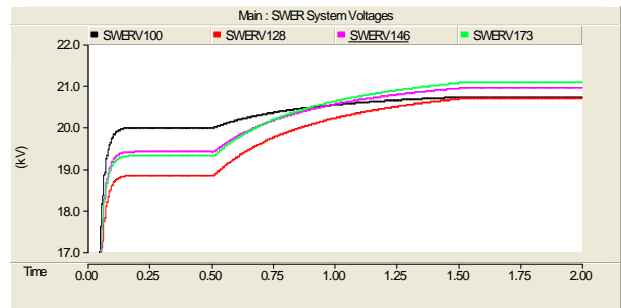


Figure 9 – Voltages without shunt reactors

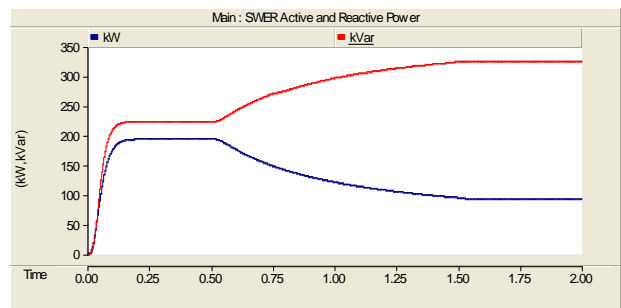


Figure 10 – Power without shunt reactors

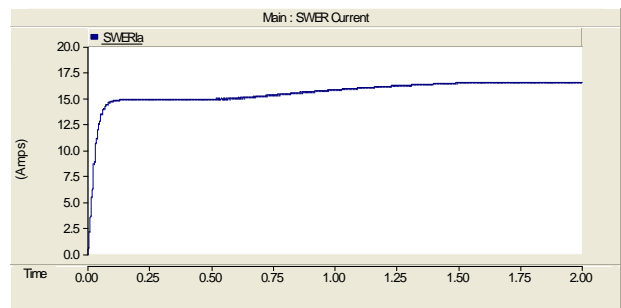


Figure 11 – Current without shunt reactors

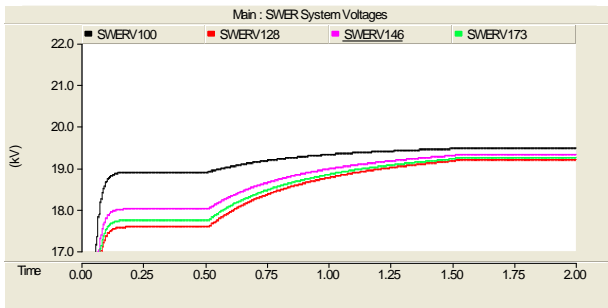


Figure 12 – Voltages with shunt reactors

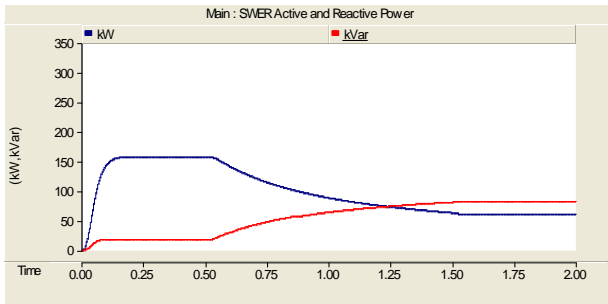


Figure 13 – Power with shunt reactors

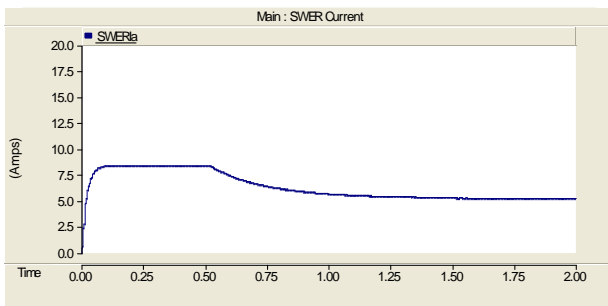


Figure 14 – Current with shunt reactors

The output graphs clearly demonstrate the voltage regulation issues being experienced. During periods of low load, significant generation of reactive power due to the Ferranti effect causes voltages to be excessive (up to +10%) without reactors. During peak load the voltage at the ends of the feeder are quite low. The shunt reactors clearly add to the load burden and worsen the voltage drop (down to - 9%). Quite clearly the shunt reactors are needed during low load periods but are not required during peak load periods. This provides opportunities to investigate alternative means of voltage regulation on SWER feeders.

The above figures have been compared with PSS Adept, the software package traditionally used by Ergon Energy to model their SWER systems. The PSCAD results are within approximately 5% of PSS Adept, which is considered sufficiently accurate for the purpose of this project, which is to investigate the performance of various voltage regulation schemes.

6. CONCLUSIONS

This paper has described the development of a model for a Single Wire Earth Return (SWER) feeder system using PSCAD including the development of a new SWER π circuit component. This PSCAD case file has been used to demonstrate voltage regulation issues that are

occurring with the existing voltage regulation strategy of employing fixed shunt reactors. This work will assist in investigating the application of alternative voltage regulation strategies including switched reactors, saturable reactors and thyristor controlled reactors.

7. ACKNOWLEDGEMENTS

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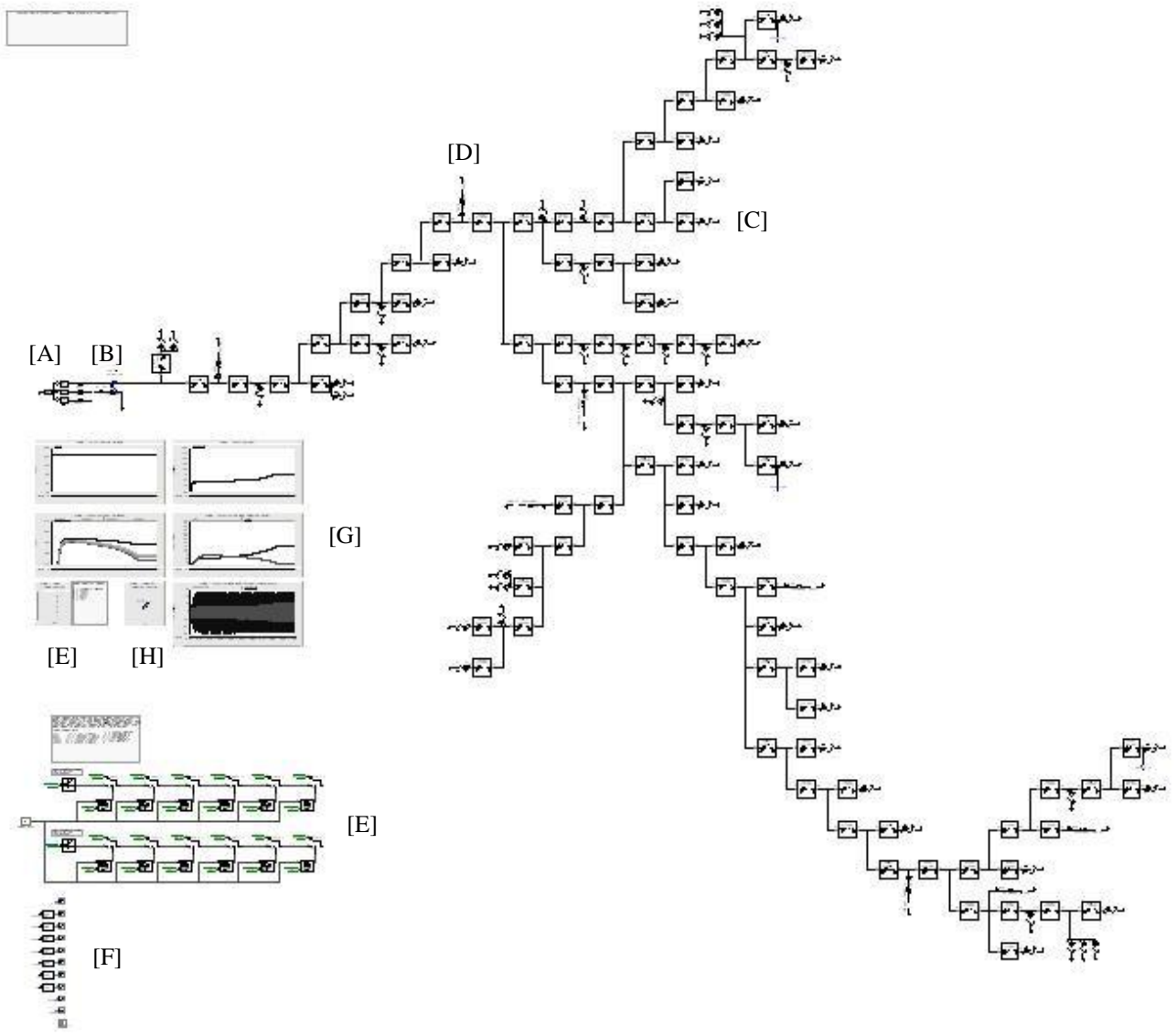


Figure 15 – Completed PSCAD case file showing the 22 kV source [A], isolation transformer [B], SWER feeder PI segments, loads [C typical], reactors [D typical], load control logic and selector [E], measurement points [F], output graphs [G] and reactor controls [H]