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Power System Stabilizer PSS4B Model for Iraqi National Grid using PSS/E Software

Hanan Mikhael Habbi*
Lecturer
Electrical Engineering Department
Engineering College- University of Baghdad
hhabbi@gmail.com

Ahmed Alhamadani
M.Sc. Student
Electrical Engineering Department, Engineering
Engineering College- University of Baghdad
Ahmedalhamadani61@yahoo.com

ABSTRACT

To damp the low-frequency oscillations which occurred due to the disturbances in the electrical power system, the generators are equipped with Power System Stabilizer (PSS) that provide supplementary feedback stabilizing signals. The low-frequency oscillations in power system are classified as local mode oscillations, intra-area mode oscillation, and interarea mode oscillations. Double input multiband Power system stabilizers (PSSs) were used to damp out low-frequency oscillations in power system. Among dual-input PSSs, PSS4B offers superior transient performance. Power system simulator for engineering (PSS/E) software was adopted to test and evaluate the dynamic performance of PSS4B model on Iraqi national grid. The results showed that after installing the PSS in a specific plant the oscillation of rotor angle, bus frequency, speed, power flow is better than without PSS during the disturbances that occurred during the simulations. All the PSS/E simulation and tests were done in the National dispatch center (NDC) laboratory, Ministry of Electricity.

Key Words: PSS4B, PSS/E, frequency oscillation, multiband power system stabilizer.

نظام مثبت القدرة متعدد المستويات PSS4B المطبق على الشبكة الوطنية العراقية باستخدام برنامج القدرة للمحاكاة PSS/E

احمد عبد الكاظم الحمداني
طالب ماجستير
قسم الهندسة الكهربائية. كلية الهندسة. جامعة بغداد

حنان ميخائيل داود
مدرس دكتور
قسم الهندسة الكهربائية. كلية الهندسة. جامعة بغداد

الخلاصة

من اجل اخماد تذبذبات الترددات المنخفضة التي تحدث في الشبكة الكهربائية نتيجة اضطرابات معينة. تم تزويد محطات التوليد بمنظومة مثبت القدرة وهذه المنظومة من شانها تغذية اشارات استرجاعية مستقرة ساندة . ان تذبذب الترددات المنخفضة في نظام القدرة يمكن تصنيفه الى تذبذبات موقعية، تذبذبات المناطق المتداخلة ،تذبذبات المناطق التداخلية. تم اختيار نوع ثنائي المدخلات ومتعدد المستويات من اجل اخماد تذبذب الترددات المنخفضة للمستويات الثلاثة العالي والمتوسط والمنخفض وهذا النوع اللذي تم

*Corresponding author
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اختياره يعرف باسم PSS4B ويمتاز هذ النوع من انظمة مثبت القدرة بادائه الانتقالي العالي.تم اعتماد برنامج محاكاة نظام القدرة الهندسي لتقييم اداء نظام مثبت القدرة للنوع اللذي تم اختياره اعلاه على جزء من الشبكة الوطنية العراقية وقد اظهرت النتائج بعد تنصيب نظام مثبت القدرة في احد المحطات بان التذبذب في زاوية الدوار ،تردد القضيب، السرعة، والقدرة المنتقلة افضل مما في حالة بدون تنصيب نظام مثبت القدرة . تم اجراء هذه المحاكاه في الممختبر الحاسوبي في مركز التشغيل والتحكم ، وزارة الكهرباء العراقية.

الكلمات الرئيسية: نظام مثبت القدرة متعدد المستويات، تذبذب التردد، PSS4B, PSS/E.

1. INTRODUCTION

Power system stability enables the power system to keep it in a state of operating equilibrium under normal operating conditions and to regain an unacceptable state of equilibrium after being subjected to a disturbance. Thus power system behavior is a measure of dynamic stability as the system adjusts to small perturbations, **Kundor, 1994**. As the number of power plants with automatic voltage regulators grew, it became apparent that the high performance of these voltage regulators had a destabilizing effect on the power system. Power oscillations of small magnitude and low frequency often persisted for long periods of time. In some cases, this presented a limitation on the amount of power able to be transmitted within the system. For this purpose, power system stabilizers (PSS) were developed to aid in damping of these power oscillations by modulating the excitation supplied to the synchronous machine, **Lokman and Haider, 2009.**

For any input signal the transfer function of the stabilizer must compensate for the gain and phase characteristics of the excitation system, the generator, and the power system, which collectively determine the transfer function from the stabilizer output to the component of electrical torque which can be modulated via excitation control, **Michael and Richard, 2008**

PSS/E is set of computational tools that are directed by the user in an interactive manner that does not solve a specific problem. By applying these tools in the appropriate sequence, a wide range of investigations can be handled for the planning and operation of electric power systems. Through the software PSS/E interface, the following functions and analyses are available: **WANGYong, et al., 2014.**

- Power flow and related network functions
- Optimal power flow and Open access
- Fault analysis and Network equivalency
- Dynamic simulation
- One-line diagrams and Program automation

Additionally, one of the most basic principles of PSS/E is that the greatest benefit can be derived from computational tools by retaining intimate control over their application. PSS/E users familiarized to such control by use of the IPLAN program language now have available the additional capability to run Python programs within PSS/E for batch control and automation of the simulation processes.

Once opened, the key elements of the user interface are the Tree View, Spreadsheet View, Diagram View and the output bar, as pointed out in **Fig.1**.

2. DUAL INPUT POWER SYSTEM STABILIZER MODEL (TYPE PSS4B)

In 2005 IEEE introduced a new standard model for Power System Stabilizers, the PSS4B. This is an advanced multi-band stabilizer that may give a better performance than the regular PSS's often used today. The new stabilizer has three separate control structures, handling different frequency bands of the low-frequency oscillations at the power system, **Anders, 2011**.

The PSS4B model represents a structure based on multiple working frequency bands as illustrated in **Fig. 2.a.** Three separate bands, respectively dedicated to the low-, intermediate- and high-frequency modes of oscillations, are used in this delta-omega (speed input) PSS. The low band is typically associated with the power system global mode, the intermediate with the inter-area modes, and the high with the local modes. Each of the three bands is composed of a differential filter, again, and a limiter. Their outputs are summed and passed through a final limiter V_{STMIN}/V_{STMAX} resulting in PSS output VST.

The PSS4B measures the rotor speed deviation in two different ways. $\Delta\omega_{L-I}$ feeds the low and intermediate bands, while $\Delta\omega H$ is dedicated to the high-frequency band. The equivalent model of these two-speed transducers is illustrated in **Fig. 2.b**. Tunable notch filters Ni(s), optionally used for turbo-generators torsional modes, are defined as illustrated in Equation (1).

$$N_i(S) = \frac{S^2+\omega_{ni}^2}{S^2+B\omega_i^2+\omega_{n_i}^2} \quad (1)$$

with ω_{n_i} the filter frequency, and $B\omega_i$ its 3 dB bandwidth. Sample data sets are illustrated in **Table 1**, which also contains a brief description of the tuning philosophy used in the PSS4B model.

3. DYNAMIC SIMULATION

A standard Dynamics simulation is performed using the Perform Dynamics Simulation dialog found under Dynamics>Simulation>Perform simulation (START/RUN). From this dialog, the Dynamics simulation can be initialized and run to any point in time, **Fig.3**. The channel output file, used to capture the output of the Dynamics simulation, is specified in the "Channel output file" field. The channel output file can be selected by entering it directly in the field or by selecting the "browse" button to the right of the field and using a standard file selector dialog to select the file. The "Run to" field defines the value of simulated TIME at which the simulation activity is to be terminated. When the dialog is brought up, this field contains the present value of simulated TIME.

4. DISTURBANCE MENU BAR ENTRIES

The following subsections describe the dialogs found in the Disturbance Menu Bar entry of PSS/E.

4.1 Apply a Bus Fault

A fault at a specified in-service bus (i.e., the bus type code must be one or two) can be applied using the Apply a Bus Fault dialog found under Disturbance>Bus fault, **Fig. 4**.

The bus to fault is specified in the “Apply fault bus” field. The bus can be specified by entering it directly in the “Apply fault at bus” field or by selecting the Select button to the right of the field and using the standard bus selector dialog to select the bus.
The "Base kV" field is set to the base voltage of the specified bus as contained in the current network. The value of fault admittance is calculated based the settings of the "Units" radio button, the impedance or admittance edit fields, and, except for faults specified in MVA, the "Base kV" edit field. The "MHO's" and "OHM's" radio buttons are enabled only if the "Base KV" field contains a positive value. When the dialog is opened, these fields are set such that a three-phase fault is applied. The specification of these data items is identical to that used in the APPLY FAULT BUS command of activity PSAS.

4.2 Apply a Line Fault

A fault at the "from" bus end of a specified branch can be applied using the Apply a Line Fault dialog found under Disturbance>Line fault, **Fig.5**. If the branch to be faulted is a non-transformer branch or a two-winding transformer, it must be in-service; if the branch to be faulted is a three-winding transformer, the winding connected to the first bus specified must be in-service.
The "Base kV" field is set to the base voltage of the specified "From" bus as contained in the working case.

4.3 Clear Fault

The faults applied using the “Apply a Bus Fault”, “Apply a Line Fault”, "Calculate and Apply a Bus Fault" and "Calculate and Apply Branch Unbalance" dialogs can all be cleared using the Clear Fault dialog found under Disturbance>Clear fault.

5. SIMULATION AND RESULTS OF PSS/E SOFTWARE ON IRAQI NATIONAL GRID

The plants which are chosen for studying the implementation of PSS/E of Iraqi national grid due to their generation values, that’s because the power system stabilizer installation and tuning costs are high so there no suitable benefit to installing PSS into small generation units.
According to NDC input file, Iraqi national grid consists of about 237 generation units (steam, gas, diesel and hydro) which are geographically distributed from Duhok to Basra, some of them are connected to 132 KV grid and the other units are connected to 400 KV grid. The simulation will be done by installing the power system stabilizer (PSS4B) in Dora power plant U3 and monitoring the performance during the disturbances in two cases with and without PSS4B. Two tests will be done, bus fault and line fault as per the types of the disturbances which are available in the PSS/E software.

5.1 Faults at Dora power station

In order to evaluate the performance of the grid under transient conditions (faults), a series of simulations were carried out on different stations for both cases with and without PSS to evaluate the performance of the system under these conditions, and to investigate the effect of adding PSS type (PSS4B) to the system oscillations resulting from these conditions. For this case, a bus fault is assumed to take place at the generation bus bar (16806) (132KV side) **Fig.6**.

The time duration of the fault is assumed to be 150 msec. The simulation was executed suggesting that the disturbance (bus fault) is utilized at time =1sec, earlier the system is running in normal steady state situations. The system behavior is studied for10 seconds (The time frame of interest in small- disturbance stability studies is of the order of 10 to 20 seconds following a disturbance).

The major concern, the effect of bus fault on the one generator is to observe the oscillations of the torque angle (generator ang1e, load ang1e, (δ)), speed, bus frequency and the active power flow osci11ation for the transmission lines linking power plants each other.

5.2 Bus Fault at Dora U3

Dora Power Station consists of four thermal units which are U3, U4, U5, and U6. U3 and U4 are Italian manufactures (Ansaldo) while U5 and U6 are Germany manufacture (Siemens).
Power system stabilizer (PSS4B) will be installed in U3 and the bus fault test will be done on the generation bus (16806) as per the coding in the input file of NDC. The major concern when bus occurred on the generation is to observe the oscillations of the 1oad ang1e (δ), speed, frequency and oscillations in active power f1ow in the transmissions 1ines linking power plants to each other. **Fig. 7.a** shows the osci11ations in generator's 1oad ang1e with and WOPSS. The behavior is improved when settling the PSS: P.O.SH WOPSS= 94.610 degree, P.O.SH WPSS= 53.275 degree and overshoot alteration = 41.335 degree.
The enhancement in variation in power flow will be illustrated in **Fig. 7b.**
P.O.SH WOPSS= 302 MW, P.O.SH WPSS= 130 MW, and over shoot difference = 172 MW. The speed variation enhancement is illustrated in **Fig. 7c.**
P.O.SH.WOPSS= 0.27287E-1 degree, P.O.SH WPSS= 0.37346E-2 degree, and over shoot difference = 0.7234 degree. Also for the frequency deviation, the enhancement is explained as illustrated in **Fig. 7d** P.O.SH WOPSS= 0.009 degree, P.O.SH WPSS= 0.0048 degree, and over shoot difference =0.0042 p.u.
A bus fault is applied to bus 16806 which is the generation bus of U3 in Dora power plant at t=1 sec and after 0.15 sec the fault cleared the **Figs.7 (a, b, c, and d)** shows that the PSS4B damps oscillation with smaller overshoot than WOPSS.

5.3 Effect of Bus Fault at Dora on Zubaidiya

In this section, the behavior of Zubaidiya power plant due to the bus faults in the Dora power plant U3as illustrated in Fig.8a. The speed, frequency, and power flow deviation due to the bus fault in two cases with and WOPSS as illustrated in the **Figs. 8 (b, c and d):**
The speed fluctuation is illustrated in **Fig.8.b** with and WOPSS. The behavior is enhanced because of PSS performance:
P.O.SH WOPSS= 0.3268E-3 degree, P.O.SH WPSS= 0.19436E-3 degree and overshoot difference = 0.00013244 pu.
For the variation in active power flow, the enhancement is explained as illustrated in **Fig. 8 c**.
P.O.SH WOPSS= 574.7 MW, P.O.SH WPSS= 568.8 MW, and over shoot difference = 5.9 MW.
And for the frequency variation, the enhancement is explained as illustrated in **Fig.8 d**.
P.O.SH WOPSS= 0.2925E-3 degree, P.O.SH WPSS= 0.19436E-3 degree, and over shoot difference =0.09814E-3 p.u.

5.4 Line Fault at Dora U3

The second disturbance that will be studied in this section is the line fault as one of the disturbances that available in the PSS/E software. The line fault will be implemented on Dora U3 (16806-16317) and the PSS4B will be installed in the same unit.

For this case, a line fault is assumed to take place at the generation bus bar (132KV side).

The time duration of the fault is assumed to be 150 msec.

The line fault disturbance is suggested to be applied at time =1sec, earlier the system is at steady state. The behavior of the system is observed for 10 sec.

The major concern, the effect of bus fault on the one generator is to observe the oscillations of the generator angle (δ), speed, bus frequency and the oscillations in active power flow in the T.L linking power plant to other power plants and the speed and bus frequency.

Fig. 9a shows the oscillations in generator's load angle with and WOPSS. The behavior is enhanced due to PSS operation:

P.O.SH WOPSS=97 degree, P.O.SH WPSS=58 degree and overshoot difference =39 degree.

While the variation in power flow, the enhancement is explained as illustrated in **Fig. 9b.**

P.O.SH WOPSS= 255MW, P.O.SH WPSS=152 MW, and over shoot difference =103 MW.

While the speed deviation, the enhancement is explained as illustrated in **Fig. 9c.**

P.O.SH WOPSS= 255MW, P.O.SH WPSS=152 MW, and over shoot difference =103 MW.

Also for the frequency deviation, the enhancement is explained as illustrated in **Fig. 9d.**

P.O.SH WOPSS= 0.0015degree, P.O.SH WPSS= 0.0006 degree, and over shoot difference =0.0004 p.u.

5.5 Effect of Line fault at Dora on Zubaidiya

In this section the behavior of Zubaidiya Power Plant due to the line faults in the Dora Power Plant U3. The speed, frequency, and power flow deviation due to the bus fault in two cases with and WOPSS as illustrated in the **Figs. 10 (a, b and c).**

Fig. 10a shows the oscillations in speed with and WOPSS. The behavior is enhanced due to PSS operation:

P.O.SH WOPSS= 0.3268E-3 degree, P.O.SH WPSS= 0.19436E-3 degree and overshoot difference = 3.6 degree.

While the variation in power flow, the enhancement is explained as illustrated in **Fig. 10b.**

P.O.SH WOPSS= 574.7 MW, P.O.SH WPSS= 568.8 MW, and over shoot difference = 5.9 MW.

Also for the frequency deviation, the enhancement is explained as illustrated in **Fig. 10 c.**

P.O.SH WOPSS= 0.2925E-3 degree, P.O.SH WPSS= 0.19436E-3 degree, and over shoot difference =0.1E-3 p.u.

6. CONCLUSIONS

Suppressing low-frequency oscillation of the power system and improving power system dynamic stability are WPSS. The PSS is working in parallel with the exciter and governor which means that during installing power system stabilizer in a specific power plant there is some tuning should be done to the exciter and governor system parameters in order to match with the power system stabilizer type that is chosen for that plant. In view of the growing complexity of power system itse1f and the computationa1 tasks required, the computational efficiency of specialty software used for such reason has become a main concern for the power manufacturing. PSS/E is one of the main simulation tools for the power industry across the world used for system analysis. Traditionally, PSS/E has been main1y used in a single computing station. From the results obtained for Iraqi super grid 400kv and 132kv based on PSS/E simulation, it is clear that the effect of the PSS is almost clear near the place of the disturbances and its effect is reduced gradually for the far stations.

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8. LIST OF SYMBOLS

PSS: power System Stabilizer.
PSS/E: power system simulation for engineering.
NDC: national dispatch center.
δ: rotor angle, generator angle, load angle
P.O.SH: peak overshot
WOPSS: without PSS
WPSS: with PSS

T.L: transmission line

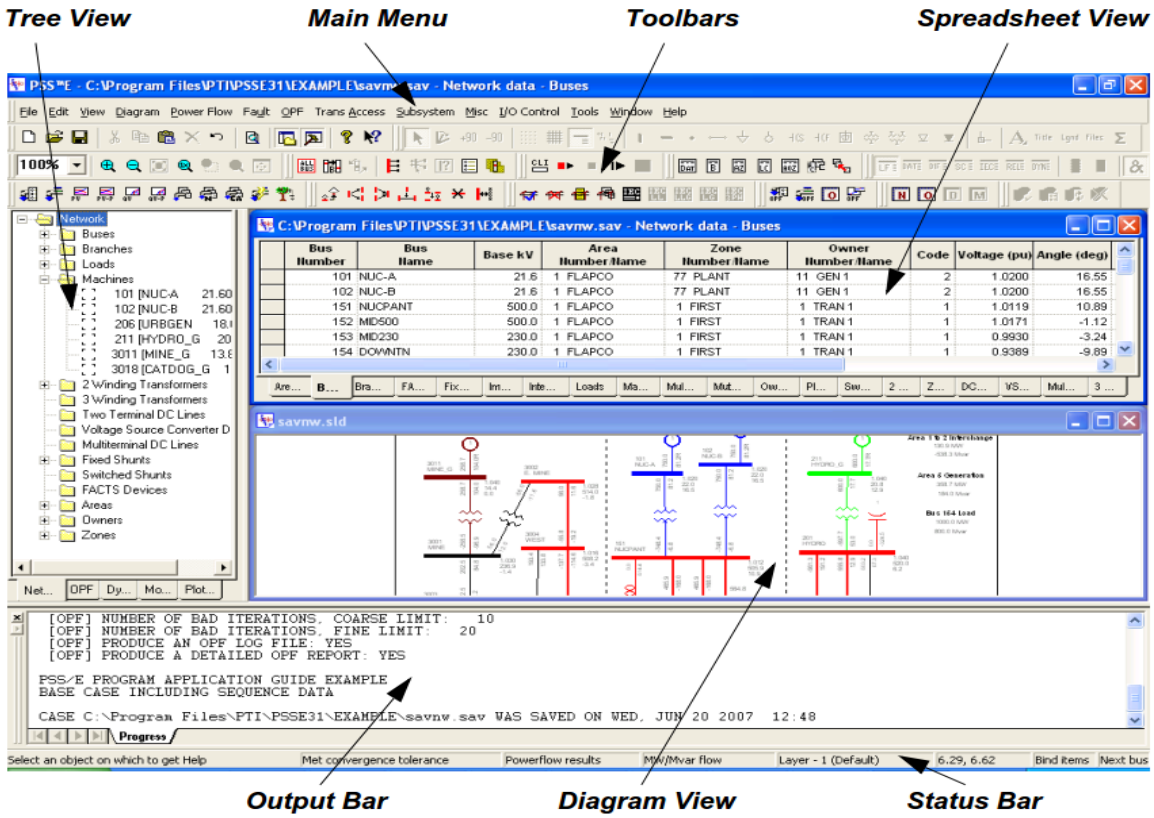

Figure 1. Key Elements of the Interface.

Table 1. Type PSS4B—MB-PSS sample data.

No.	Param.	value	No.	Param.	value	No.	Parameter	value
1	KL	7.5	15	KI	30.0	29	KH	120.0
2	KI	30.0	16	KI1	66.0	30	KH1	66.0
3	KH	120.0	17	KI2	66.0	31	KH2	66.0
4	FL	0.07	18	KI11	1.0	32	KH11	1.0
5	FI	0.7 Hz	19	KI17	1.0	33	KH17	1.0
6	FH	8.0 Hz	20	TI1	0.1730	34	TH1	0.01513
7	KL	7.5	21	TI2	0.2075	35	TH2	0.01816
8	KL	7.5	22	TI7	0.2075	36	TH7	0.01816
9	KL1	66.0	23	TI8	0.2491	37	TH8	0.02179
10	KL2	66.0	24	VIMAX	+0.60	38	VHMAX	+0.60
11	KL11	1.0	25	VIMIN	–0.60	39	VHMIN	–0.60
12	KL17	1.0	26	VSTMAX	+0.15	40	VLMAX	+0.075

13	TL1	1.730	27	VSTMIN	–0.15	41	VLMIN	–0.075
14	TL2	2.075	28	TL7	2.075	42	TL8	2.491

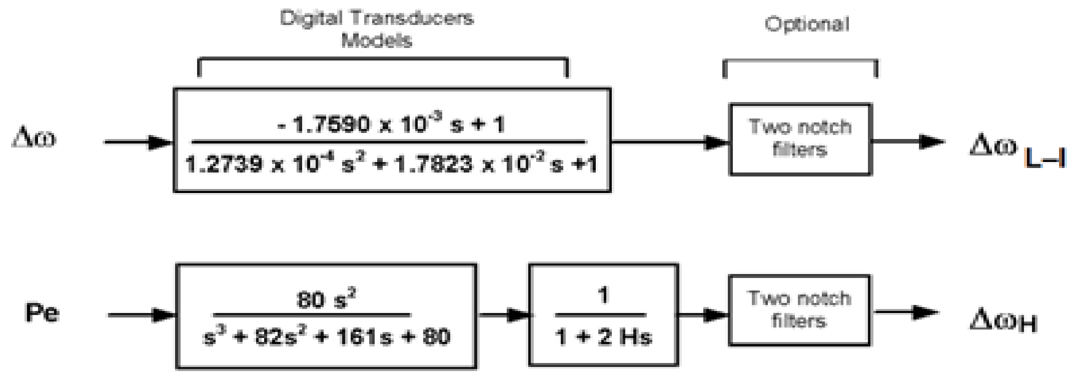

Figure 2.a Type PSS4B—MB-PSS speed deviation transducers.

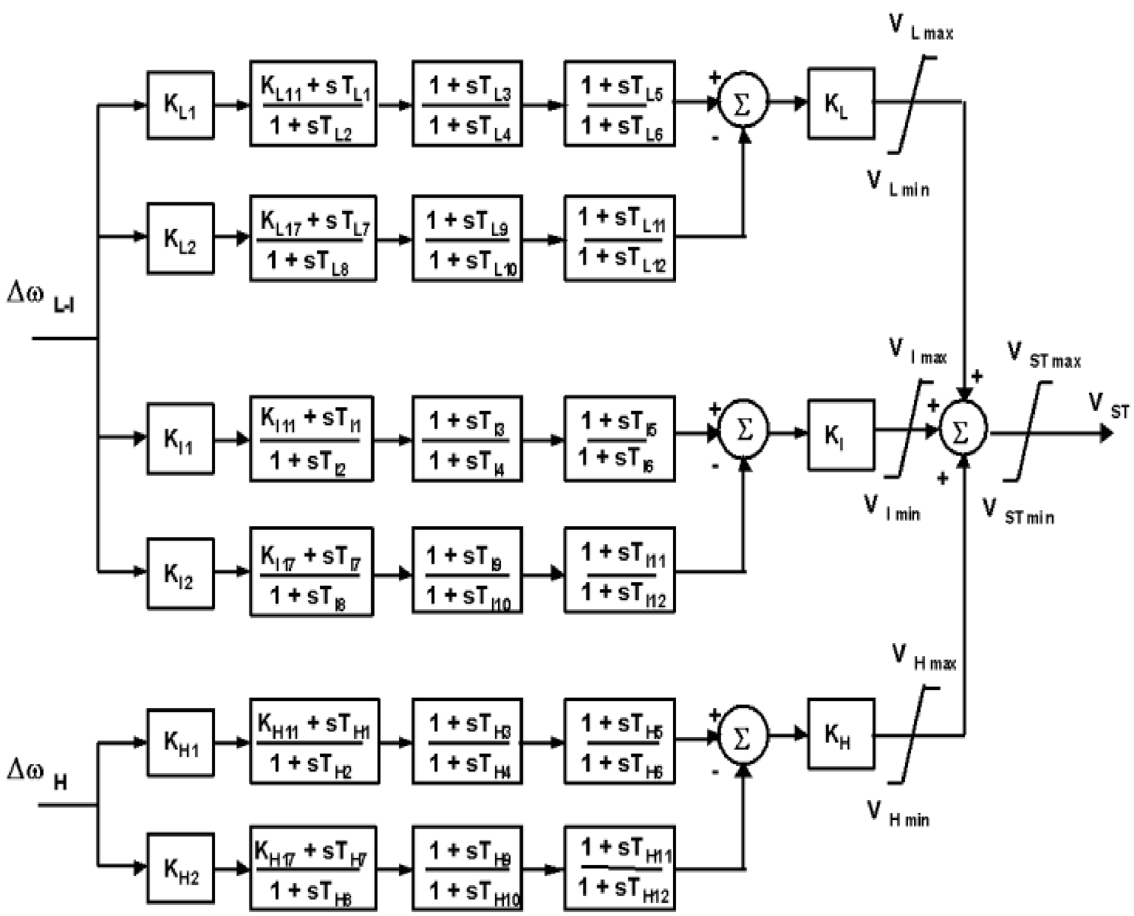

Figure 2.b Type PSS4B—Multi-band PSS.

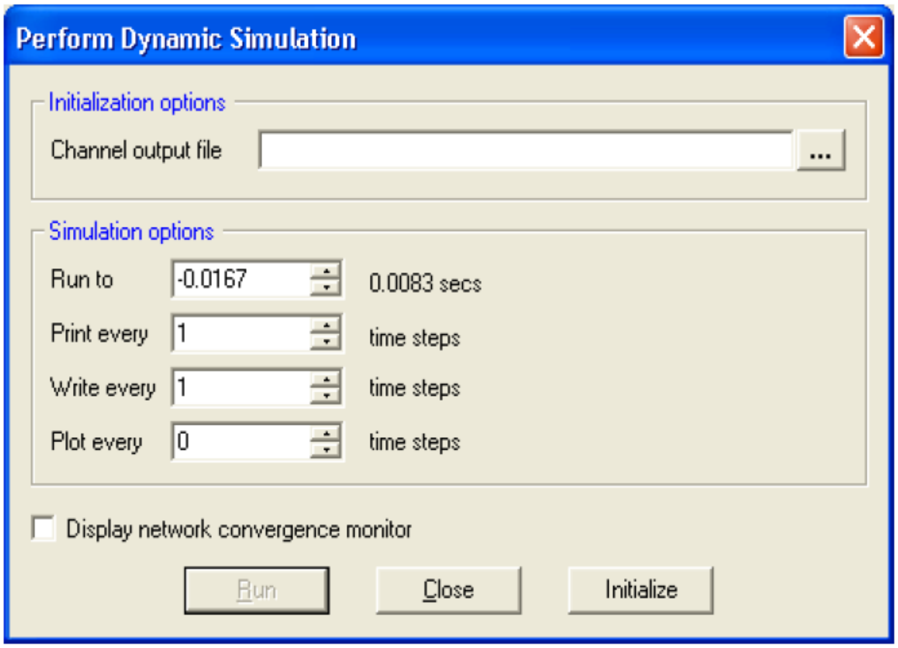

Figure 3. Perform Dynamic Simulation Dialog.

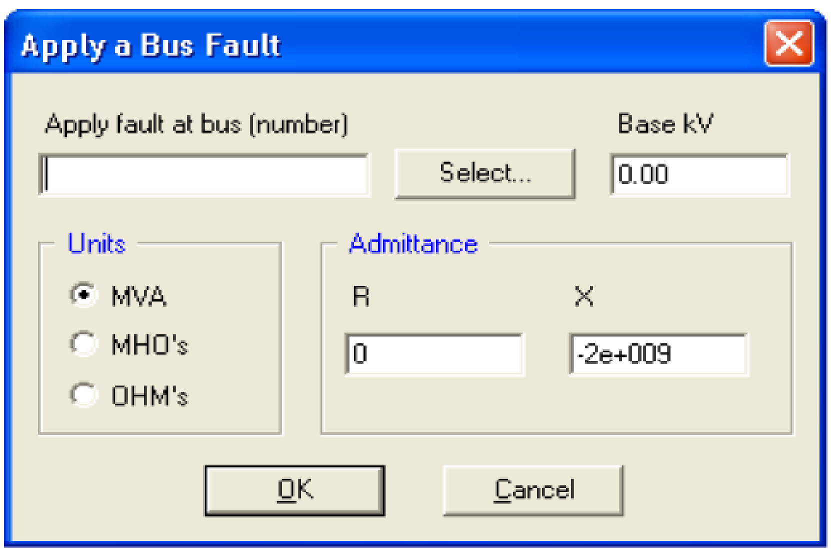

Figure 4. Apply a Bus Fault Dialog.

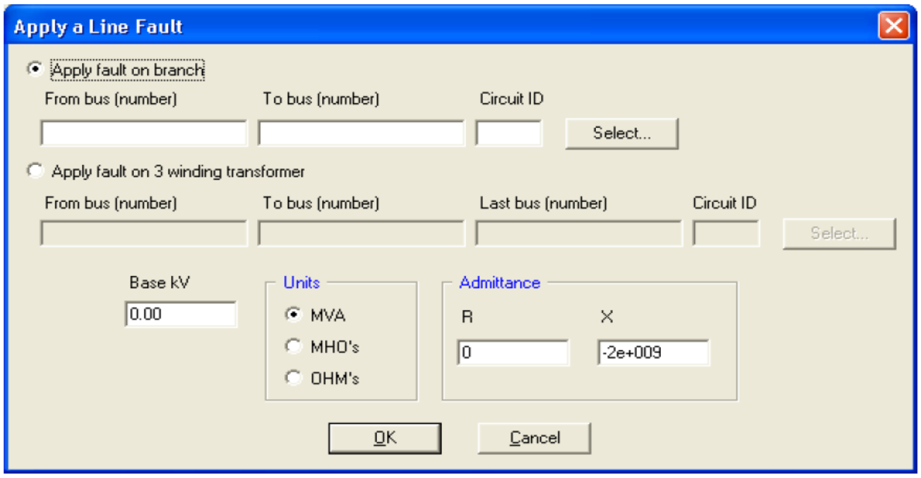

Figure 5. Line Fault Dialog.

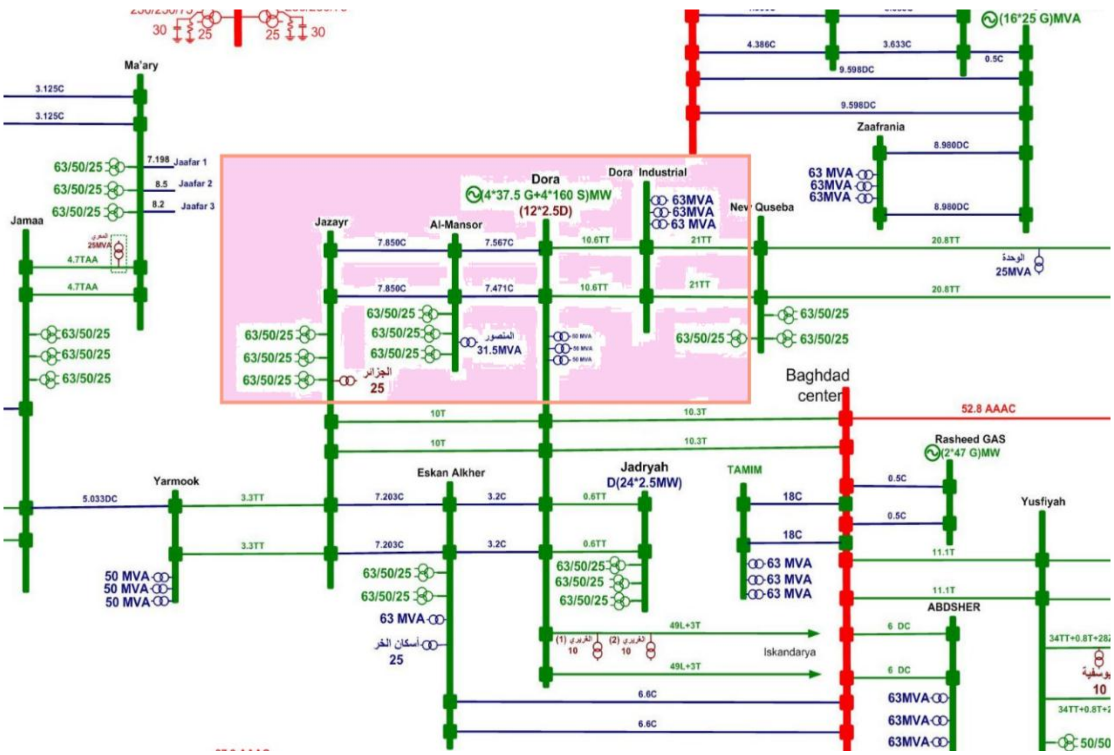

Figure 6. Dora generation bus 132KV.

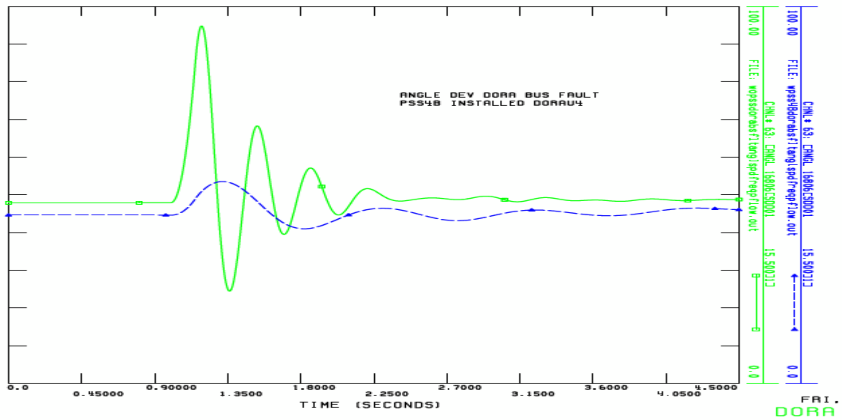

Figure.7. a Oscillations in the angle at Dora Power Station U3 for bus fault.

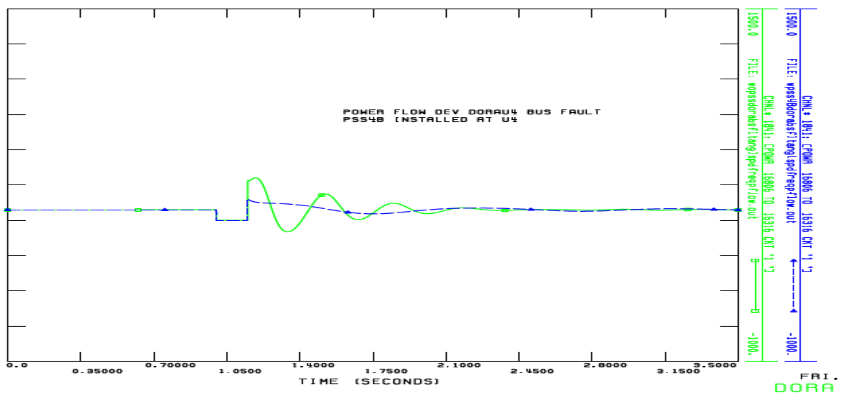

Figure 7.b Oscillations in power flow at Dora power station U3 for bus fault.

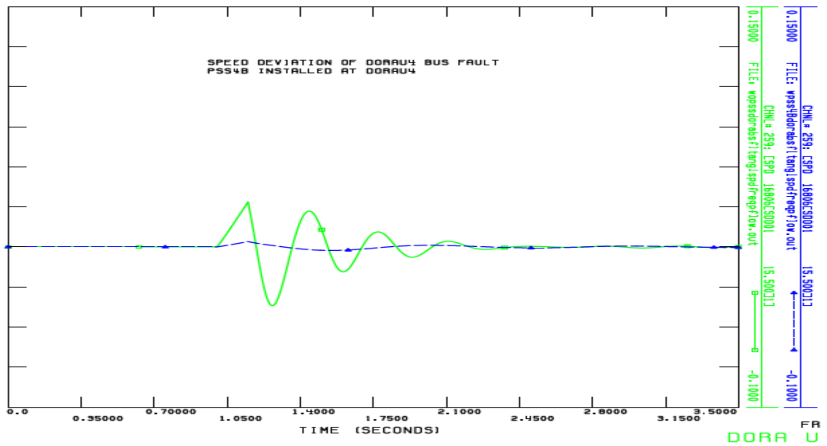

Figure 7.c Oscillations in speed at Dora Power Station U3 for bus fault.

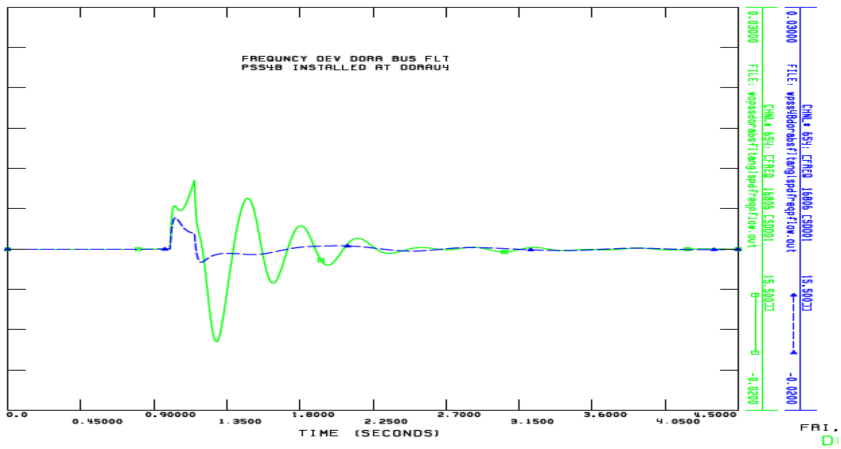

Figure 7.d Oscillations in frequency at Dora Power Station U3 for bus fault.

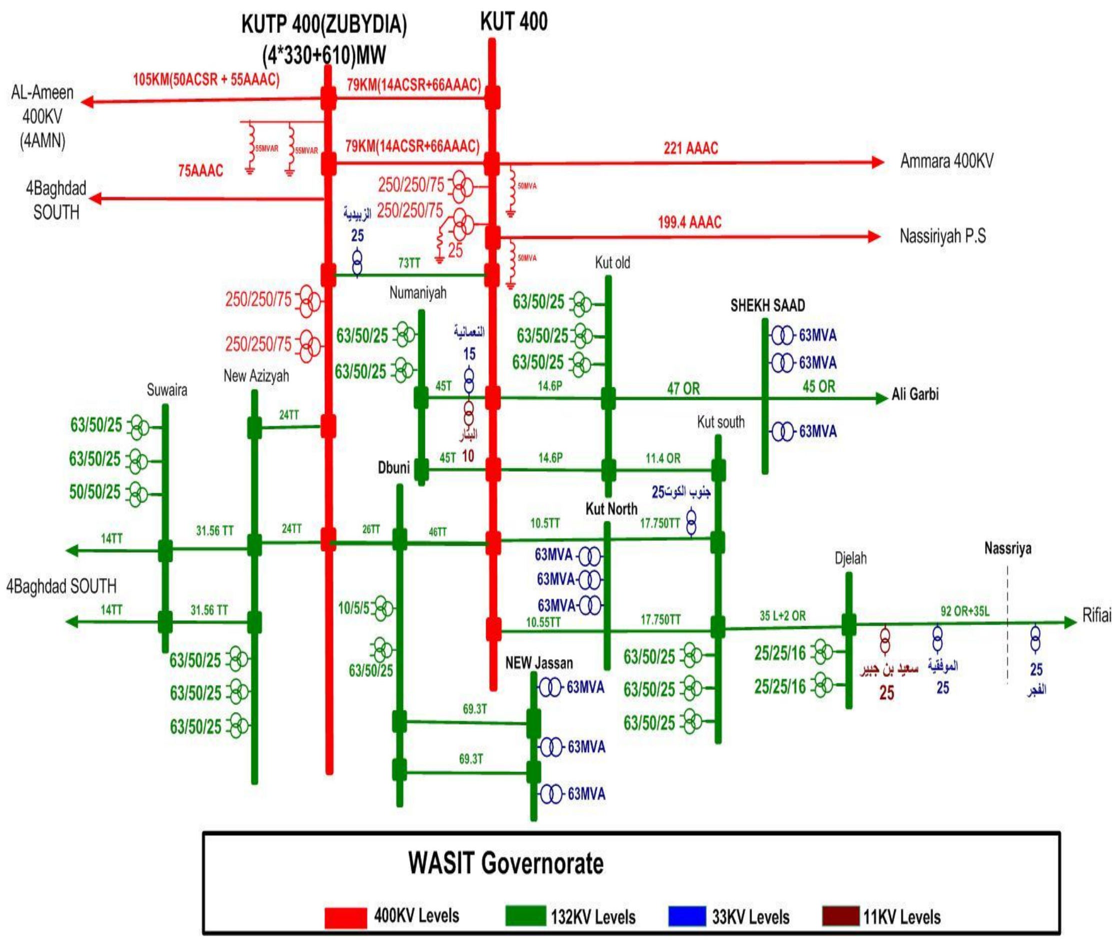

Figure 8.a Single line diagram of Zubaidiya Power Plant with 400 KV grid.

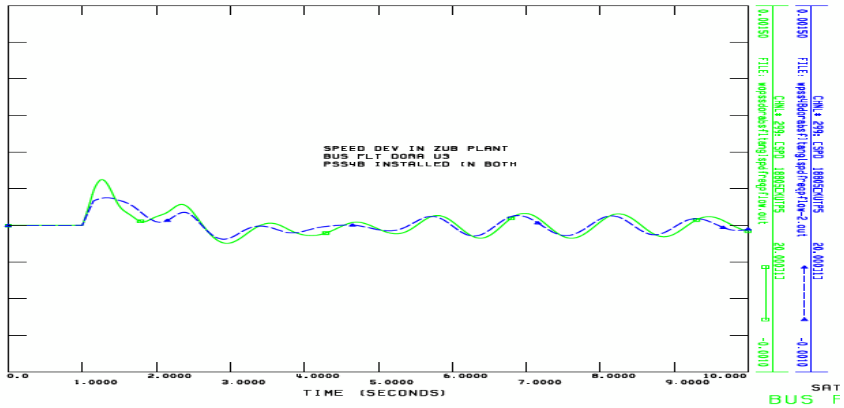

Figure 8.b Oscillations in speed at Zubaidiya Power Station for bus fault at Dora U3.

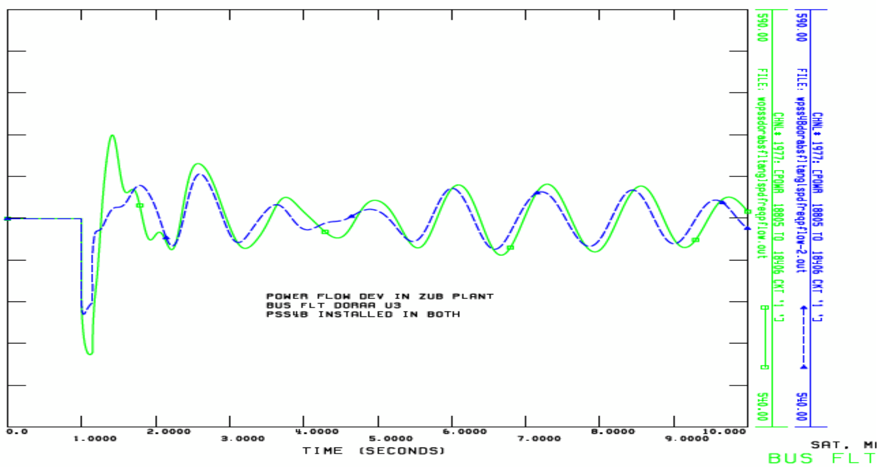

Figure 8.c Oscillations in power at Zubaidiya Power Station for bus fault at Dora U3.

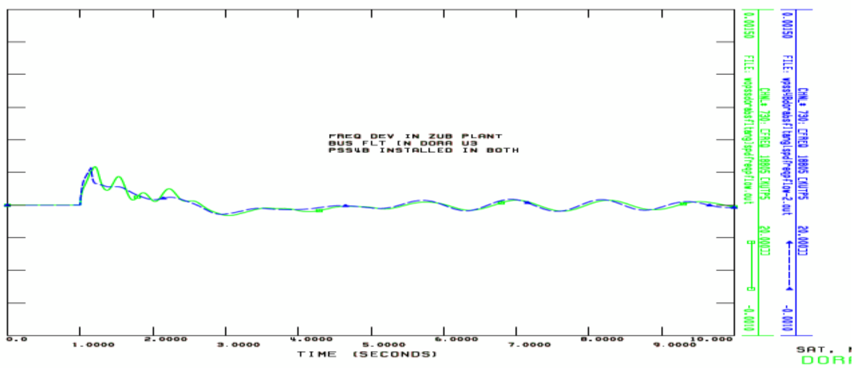

Figure 8.d Oscillations in frequency at Zubaidiya Power Station for bus fault at Dora U3.

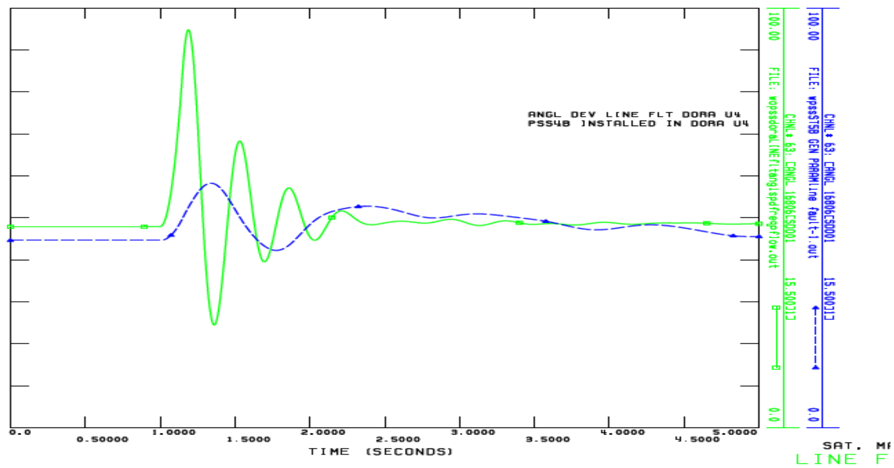

Figure 9.a Oscillations in load angle at Dora bus bar for a line fault in Dora U3.

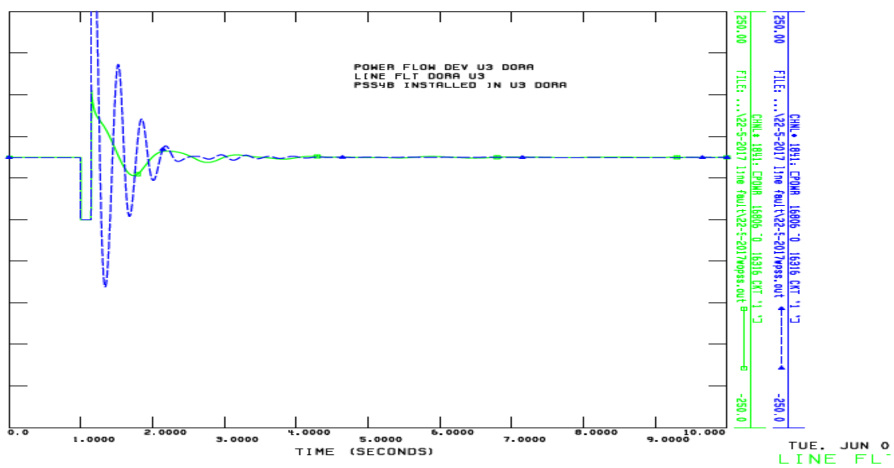

Figure 9.b Oscillations in power flow at Dora bus bar for a line fault in Dora U3.

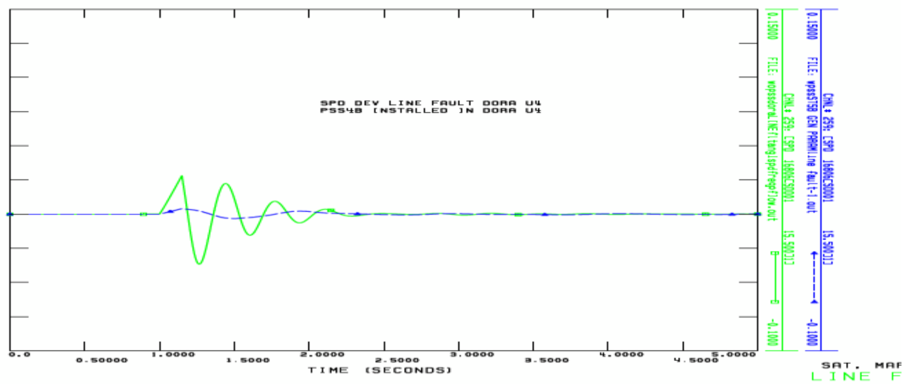

Figure 9.c Oscillations in speed at Dora bus bar for a line fault in Dora U3.

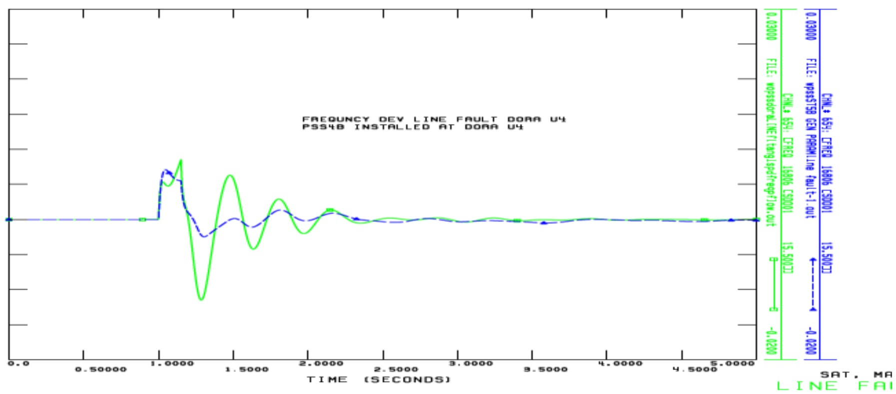

Figure 9.d Oscillations in frequency at Dora bus bar for a line fault in Dora U3.

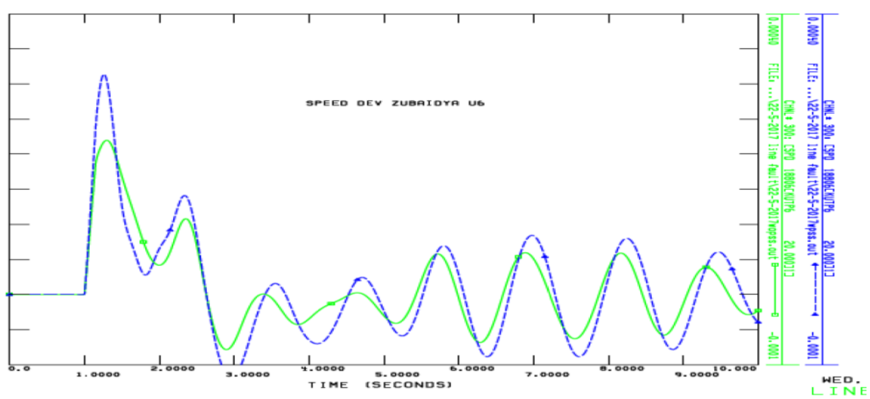

Figure10.a Oscillations in speed at Zubaidiya power station for line fault at Dora U3.

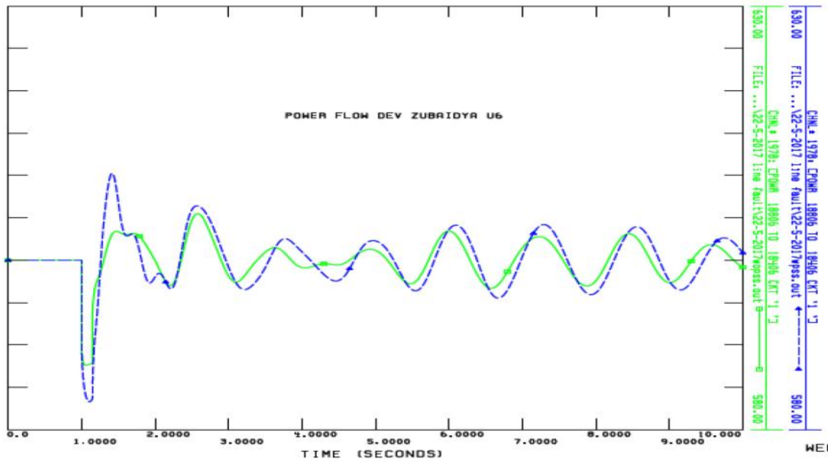

Figure 10.b Oscillations in power at Zubaidiya Power Station for line fault at Dora U3.

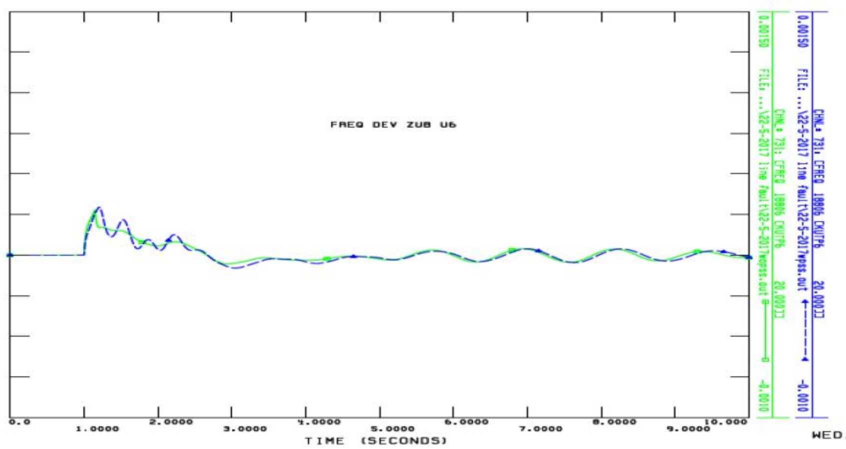

Figure 10.c Oscillations in frequency at Zubaidiya Power Station for line fault at Dora U3.