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Simulation of Synchronous Machine in Stability Study for Power System: Garri Station as a Case Study

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Abstract- This paper aimed to investigate the effectiveness of an adaptive artificial intelligence on enhancing the stability of gas turbine-Garri Power Station, which is designed to generate about 38MW. Fuzzy logic method controller was proposed based on stabilizer to enhance the power system stability. Linguistic rules and fuzzy inference mechanism are utilized to tune the controller parameters in different operating states. The proposed controller was applied to a single machine infinite bus system, represented by Gas Turbine-Garri Power Station (GPS). Simulation studies have been carried out using TILLSHELL software. The simulation results demonstrated that the proposed control scheme performs well and strongly control the power system under different loading conditions, disturbances and system parameter variations. The proposed controller is robust and more suitable for damping of low frequency oscillation and more effective in improving dynamic stability and voltage profile than the conventional systems.

Keywords: *Gas Turbine, synchronous machine, fuzzy controller.*

المستخلص:

تؤثّر تذبذبات النظام الكهربائية على إستقرار وثبات النظام ، قد تؤدى إلى فشل النظام أذا لم يسيطر عليها بشكل صحيح. وعليه ان أغلب أنظمة الطاقة الكهربائية تستخدم نظرية السيطرة الخطيّة الكلاسيكية والتى تستند على النموذج الخطي . يهدفَ هذا البحث الى تقديم طريقة جديد فى تصميم وتطبيق نظام تحكم يعتمد على المنطقِ الضبابيِ وذلك من خلال تُطوّير نظريةَ التحكمِ الرياضيةِ الكلاسيكيةِ المرتبطةِ بنظام التحكم التقليدية لتحسين إستقرارية وأداء المولد الكهربائيِ . أستخدمت هذه الطريقة لتحسين أداء إحدى مولدات محطة قرى لتوليد الكهرباء, اعتمد المنطق الضبابى على التحكم فى وسائلِ العضويةِ الضبابيةِ على الترددِ وفولطيةِ المولّدِ المدروسةِ. تم اختبار ومقارنة نظام التحكم الضبابى مع الانظمه التقليدية, وقد ظهر جليا تحسين عملية تخميد التذبذات للاشارات العابره المختلفة.

Introduction

Power system oscillations affect system stability and they may lead to failure if the system is not properly controlled. Most of power system stability in electric power systems employs the classical linear control theory approach based on a linear model of a fixed configuration of the power system.

Uncertainty in the form of ambiguity makes the real world a complex place. Humans have been able to address this problem of ambiguity with their ability to think and adapt to an ever changing environment. Fuzzy logic, as one of the principal elements of artificial intelligence is playing a key role in dealing with uncertain and imprecise information (1). It was designed mathematically to represent the vagueness and uncertainty of linguistic problems; thereby obtaining formal tools to work with intrinsic imprecision in different type of problems. It is considered as a generalization of the classic set theory. The main motivation behind fuzzy logic was the provision of a framework to represent human knowledge in which imprecision is a common feature. Artificial intelligent system based fuzzy method has an active research topic in automation and control theory. It provides a systematic method to incorporate human experience and implement nonlinear algorithms characterized by a series of linguistic statements into the controller (2, 3).

In power system studies, there are three principal control systems that directly affect a synchronous generator: the boiler, governor, and exciter controller. These factors should be addressed before proceeding to design any simulation program for power system .A schematic diagram of the necessary components that affected on the simulation procedure are shown in Figure 1.

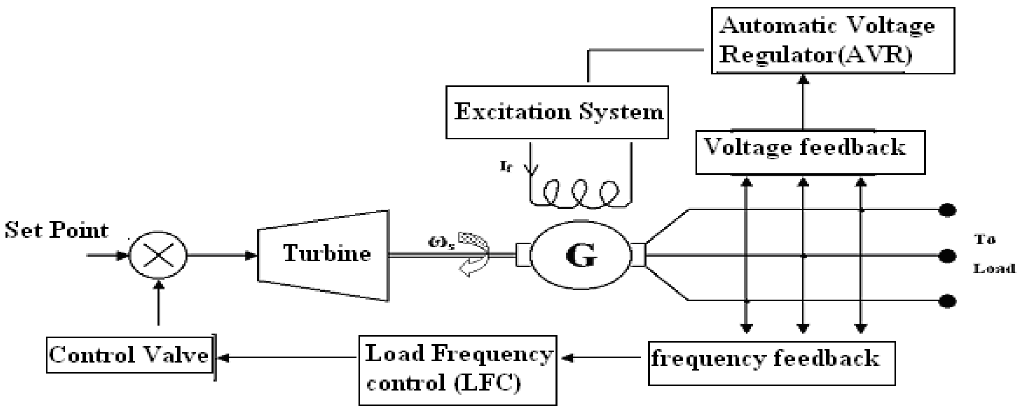


Figure 1: Basic controls of a generator

Most of Power System Stabilizers (PSS) in use in electric power systems employ the classical linear control theory approach based on linear models of fixed configuration of the power system. Such a fixed-parameter controller, called a conventional PSS (CPSS), is widely used in existing power systems and has made a great contribution in enhancing power system dynamics stability (4) which shown in Figure 1. The parameters of CPSS are determined based on a nominal operating point where they can provide good performance. Since power systems are highly non-linear, with configurations and parameters that change with time, the CPSS design based on the linearised model of the power system cannot guarantee its performance in a practical operation environment (5, 6). The common structures of PSS are:

a. Lead-lag structure or conventional PSS (CPSS)
b. Proportional Integral Derivative (PID) structure.
c. Other structure based on optimal, adaptive, variable structure, intelligent...etc. The common input signals used are the speed, frequency, voltage, electric and accelerating power deviations. However, PSS can be either conventional PSS (one-band PSS, Figure 2) which is (analog or digital) or multi-band PSS as shown in Figure 3.

To improve the performance of CPSS, numerous techniques have been proposed for their design such as using intelligence optimization methods (fuzzy, neural networks, genetic algorithm and other non-linear techniques).

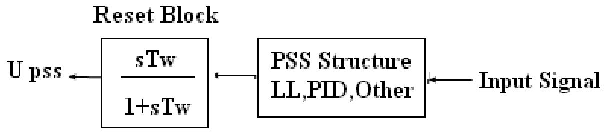


Figure 2: PSS structure

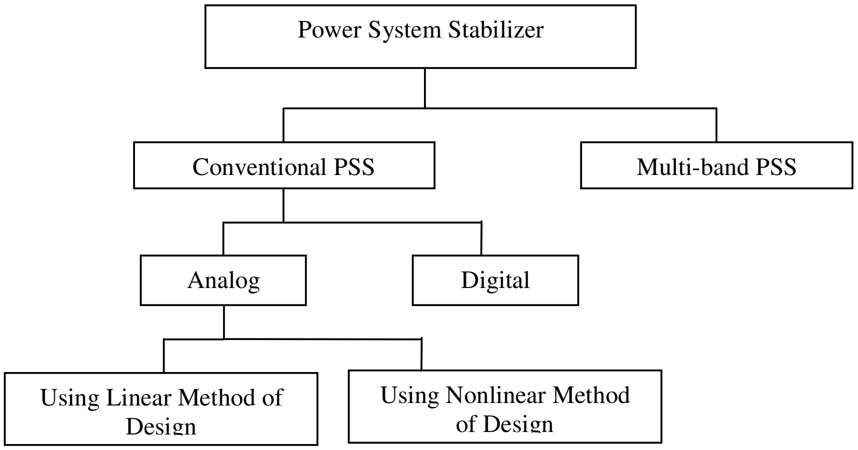


Figure 3: Multi types of PSS

Fuzzy logic

Technological innovations in soft computing techniques have brought automation capabilities to new levels of applications. Conventional control theory is based on mathematical models that describe the dynamic behavior of process control systems. Fuzzy logic is a flexible approach to conventional controllers. This logic was developed based on Lofti Zadeh's 1960s fuzzy set theory (5), which was motivated mainly by the conviction that the traditional analysis methods were inadequate to describe phenomena whose constraints were not related by differential equations. This theory provides a way of representing the vague notions through the element and its membership.

This method dealing on what the system should do rather than trying to model how it works. So fuzzy logic is the logic on which fuzzy controller is based, dealing with concept of completely truth and they are called the Zadeh operators, usually uses IF/THEN rules (3). The major concept in fuzzy logic is the linguistic variable and membership functions. Where a linguistic variable was introduced to process the natural language .The concept of membership function is to describe these linguistic values in terms of numerals. So controllers based on the fuzzy logic give the linguistic strategies control conversion from expert knowledge in automatic control strategies.

So the fuzzy logic controllers are rule-based controllers. The basic configuration of the FLC can be simply represented in four parts, as shown in Figure 4.

Fuzzification

Fuzzification is a process in which the inputs are classified to corresponding linguistic terms to get degree of fulfillment. It means adding uncertainty by design to crisp sets or to sets that are already fuzzy. A triangular membership function was used which could be compressed or expanded, but not when rule re-insertion was used.

Knowledge base

The main tasks of designing control knowledge base are:

a. **Database**: The database provides necessary definitions to define linguistic control rules and fuzzy data manipulation in an FLC.
b. **Linguistic (fuzzy) control rule base** The rule base characterizes the control goals and control policy of the domain experts by means of a set of linguistic control rules.

Decision-Making Logic (DML)

The Decision-Making Logic is the kernel of an FLC It has the capability of simulating human decision-making based on fuzzy concepts, implication and the rules of inference in fuzzy logic. Decision-making logic determines how the fuzzy logic operations are performed and together with the knowledge base determine the outputs of each fuzzy IF- THEN rules. Hence the main part of the fuzzy controller for design is the rule – base, in which it represents a human expert "in –the - loop". Therefore information's that loaded into the rules in the rule – base may come from an actual human expert, who spent a long time learning how to control the process.

Defuzzification

Last step, as the name suggests, the defuzzifier's task is the reverse operation to the fuzzifier. Which covers the inferred decision forms the linguistic variables back the numerical values, or it convert the FLC inferred control actions from fuzzy values to crisp values. This process depends on the output fuzzy set, which is generated from the fired rules. The performance of the FLC depends very much on the defuzzification process. This is because the overall performance of the system under control is determined by the controlling signal that the system universe. Defuzzifier types are: centroid defuzzifier, center average defuzzifier and min-maximum defuzzifier.

Fuzzy-Logic Based Power System Stabilizer

A FLC is a kind of a state variable controller governed by a family of rule and a fuzzy inference mechanism. The FLC algorithm can be implementation using heuristic strategies, defined by linguistically describe statements. The fuzzy logic control algorithm reflects the mechanism of control implemented by people, without using a mathematical model the controlled object, and without an analytical description of the control algorithm. Figure 5, shows block diagram of synchronous generator and FLC loops. The fuzzy logic controllers apply to maintain the signals in order to keep them constant according to pre-established values. The fuzzy controller used in power system stabilizer is normally a two-input and a single-output component. It is usually a Multi- Inputs and Single Outputs (MISO) system (9, 10).

As shown in Figure 6 it consists of the following units:

1. Synchronous machine (AC-generator)
2. Governor controls the steam/gas power amount admitted to the turbine.
3. The excitation system controls the generated EMF of the generator and therefore controls not only the output voltage but the power factor and current magnitude as well.

Fuzzy Logic Controller

The fuzzy controller is the heart of the system, it makes logic decisions depending on the input and output behavior of the generating unit (11, 12). The online system consists or needs a transformer to step-down signals and measurement circuits. The generator output passes though measurement circuits into the computer, for controlling, to control circuits. Therefore FLC is software program that interacts with the generator such that the output of the generator is maintained at specific values.

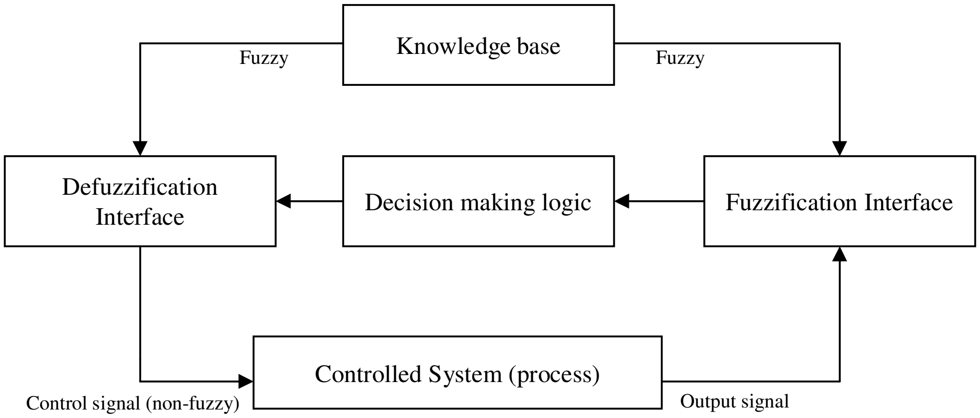


Figure 4: Principle Design Fuzzy logic

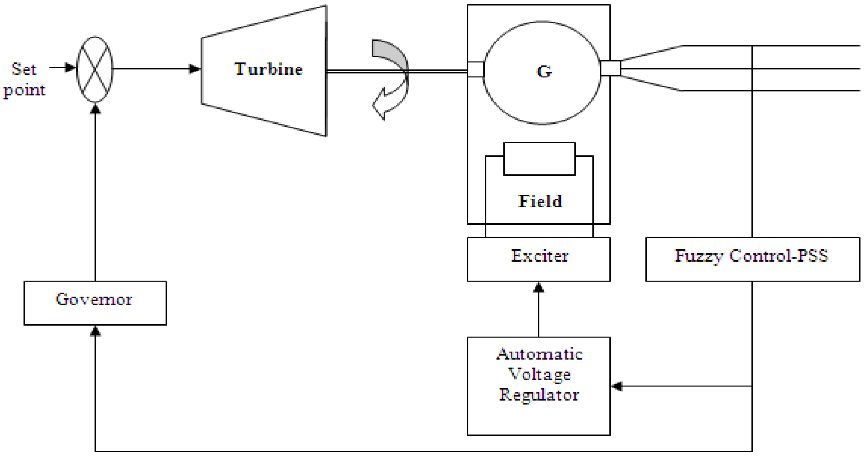


Figure 5: Block diagram of synchronous generator and FLC loops

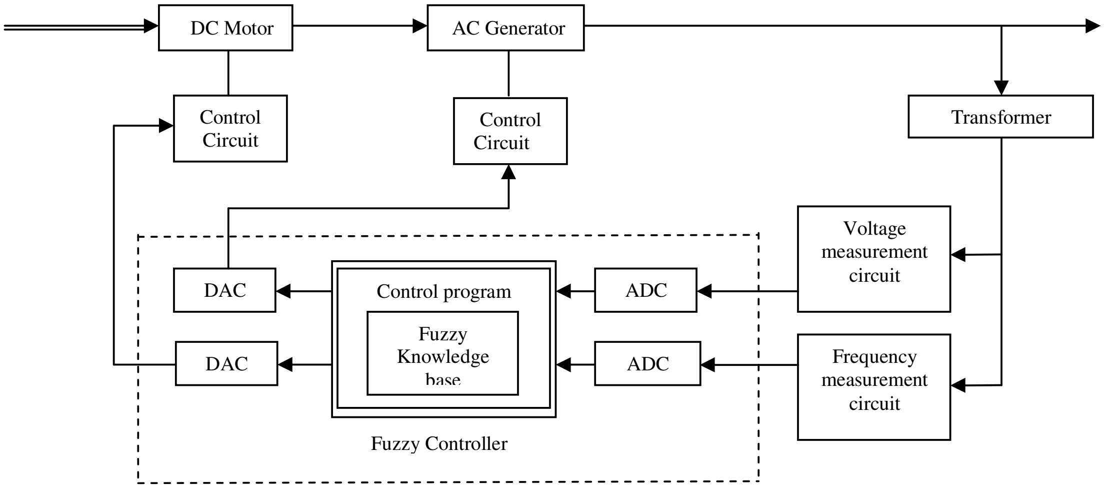


Figure 6: Block diagram of FLC connected with system

After modifying or maintaining the signal through the computer, control circuit that interfacing the FLC with the machines. Signals convert form digital to analogue (DAC) should be understood by the machine, in order to complete the loop of controlling operation. In the design of fuzzy-logic controllers shown in Figure 6 unlike most conventional methods, a mathematic model is not required to describe the system under study. It is based on the implementation of fuzzy logic technique to power system stabilizer (PSS) to improve system damping. The effectiveness of the fuzzy logic PSS in a single machine infinite bus is demonstrated by the TILL Shell Software. The performance of fuzzy logic PSS is compared with the conventional power system stabilizer (CPSS). The time-domain simulation performed on the test system will be used to study the nonlinear response following the steady state operation and large disturbance [8].

Case study: synchronous generator-Garri Power Station:

Considering a single machine connected by a transmission line to an infinite bus power system as the Figure 5.

The purpose of this work is the development of a fuzzy controller (software) to simulate the automatic voltage and frequency behavior. The proposed approach was single machine infinite bus system designed to generate 38MW. One type of this system is used in gas plant Garri-station .The simulation was performed using TIL Shell software in fuzzy system environment; the data of the system are given in Appendix A.

The controller has been incorporated with 25 rules, a triangular membership function was used which could be compressed or expanded and the system simulated with different values of the parameter considered, then compared with the nominal value (real value). The simulation results were obtained as shown in Table 1.

Table 1: The outputs for both controllers (CPP&FLC)

TIME	MW	FLC	TIME	MW	FLC	TIME	MW	FLC	TIME	MW	FLC
1:00	24.3	24.84	**4:00**	24.9	28.00	**7:00**	23.2	28.00	**10:00**	35.5	30
1:15	27.7	26	**4:15**	26.9	28.00	**7:15**	25.6	28.00	**10:15**	31.8	30
1:30	29.8	26.53	**4:30**	28.9	28.00	**7:30**	28.6	28.00	**10:30**	28.7	30
1:45	22.0	26.90	**4:45**	25.9	28.00	**7:45**	36.4	28.00	**10:45**	25.3	28
2:00	25.4	28.00	**5:00**	22.8	28.00	**8:00**	35.3	30.00	**11:00**	22	28
2:15	25.3	28.16	**5:15**	22.8	28.00	**8:15**	35.3	30.00	**11:15**	22.1	28
2:30	25.2	28.00	**5:30**	22.8	28.00	**8:30**	35.3	30.00	**11:30**	22.3	28
2:45	25.1	28.00	**5:45**	22.9	28.00	**8:45**	35.3	30.00	**11:45**	22.4	28
3:00	25	28.00	**6:00**	22.9	28.00	**9:00**	35.4	30.00	**12:00**	22.6	28
3:15	24.5	28.00	**6:15**	22.9	28.00	**9:15**	35.4	30.00	**12:15**	22.6	28
3:30	24.9	28.00	**6:30**	23.8	28.00	**9:30**	35.4	30.00	**12:30**	22.6	28
3:45	24.9	28.00	**6:45**	23.5	28.00	**9:45**	35.4	30.00	**12:45**	22.4	28

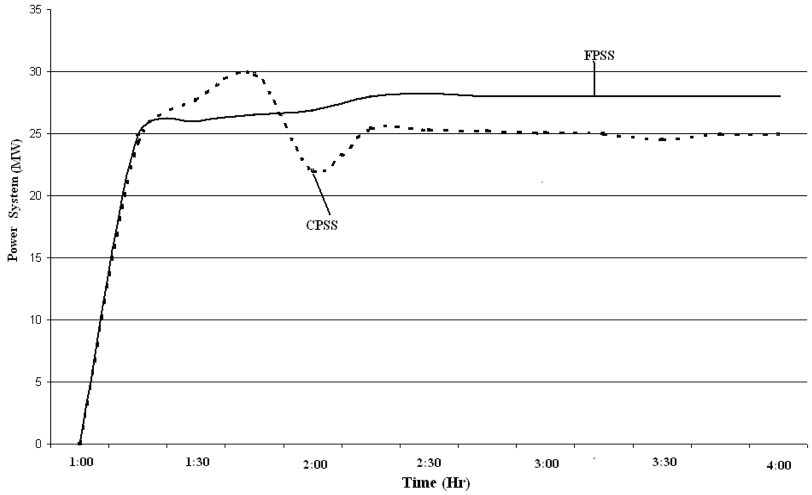


Figure 7: Slip Response of CPSS & FPSS.
Time interval is 0:15 (1:00 – 3:45)

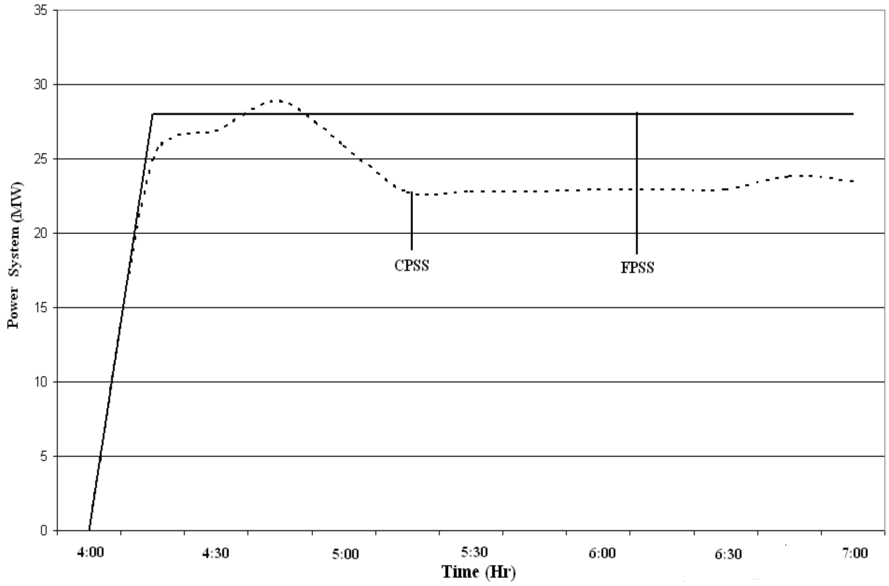


Figure 8: Slip Response of CPSS & FPSS.
Time interval is 0:15 (4:00 – 6:45)

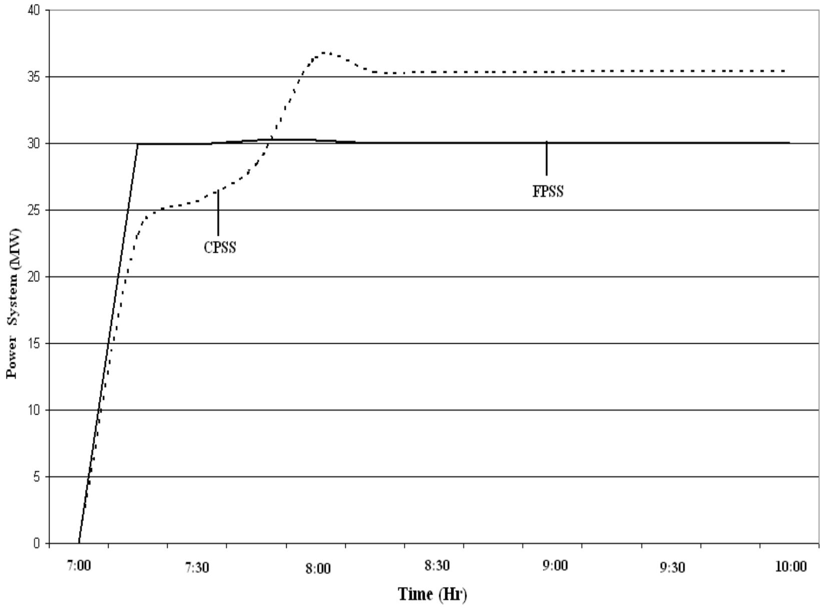


Figure 9: Slip Response of CPSS & FPSS.
Time interval is 0:15 (7:00 – 9:45)

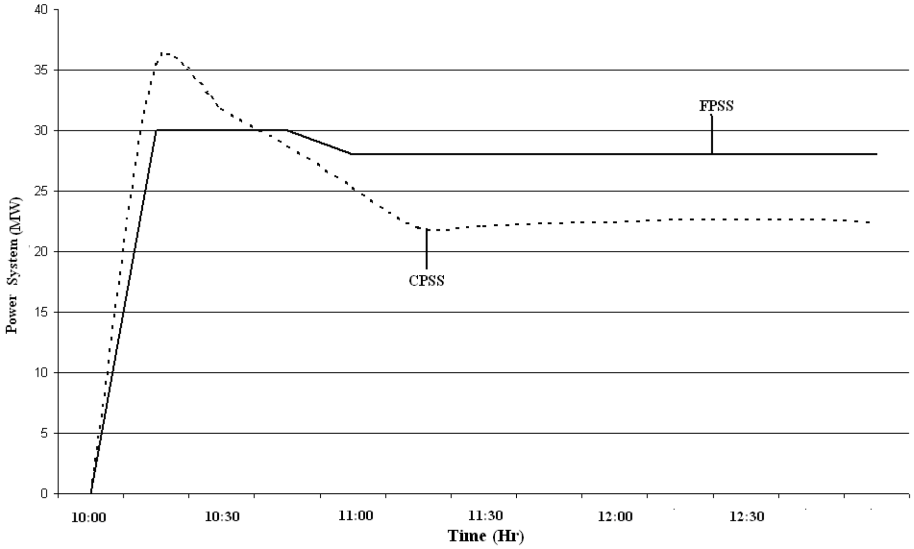
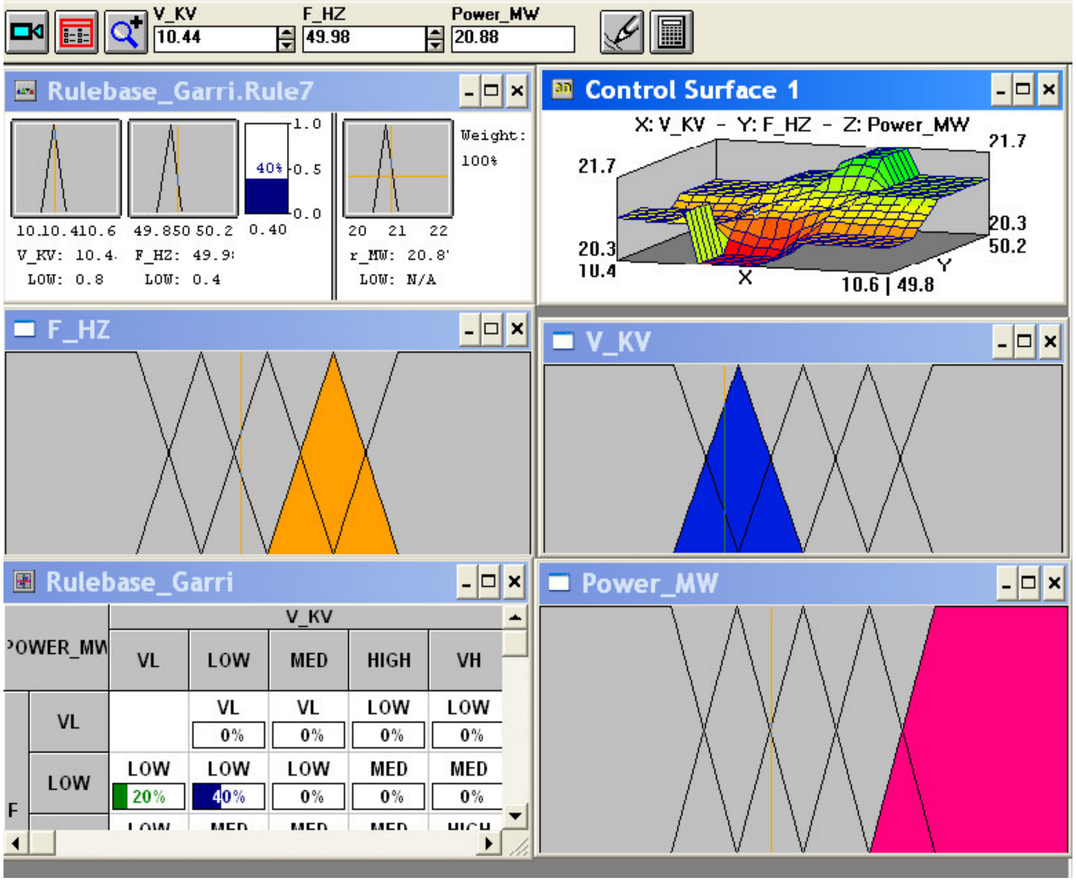


Figure 10: Slip Response of CPSS & FPSS.
Time interval is 0:15 (10:00 – 12:45)



V_KV: 10.44

F_HZ: 49.98

Power_MW: 20.88

V_KV: 10.4

LOW: 0.8

F_HZ: 49.9

LOW: 0.4

r_MW: 20.8

LOW: N/A

POWER_MW		V_KV				
		VL	LOW	MED	HIGH	VH
F	VL		VL 0%	VL 0%	LOW 0%	LOW 0%
	LOW	LOW 20%	LOW 40%	LOW 0%	MED 0%	MED 0%

Figure 11: TILL Shell software results

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Appendix A

Stability of power system over time

Time	Frequency	Voltage	MW	Time	Frequency	Voltage	MW
1:00	50.02	10.44	24.3	7:00	50.02	10.48	23.2
1:15	50.05	10.45	27.7	7:15	49.99	10.49	25.6
1:30	50.01	10.46	29.8	7:30	49.99	10.48	28.6
1:45	50.02	10.47	22.0	7:45	50.02	10.49	36.4
2:00	50. 03	10.49	25.4	8:00	50.05	10.54	35.3
2:15	50.1	10.47	25.3	8:15	50.06	10.54	35.3
2:30	50.02	10.48	25.2	8:30	50.08	10.52	35.3
2:45	50. 04	10.48	25.1	8:45	50.12	10.48	35.3
3:00	50.02	10.48	25	9:00	50.13	10.48	35.4
3:15	50.05	10.48	24.5	9:15	50.12	10.54	35.4
3:30	50.04	10.48	24.9	9:30	50.06	10.54	35.4
3:45	50.05	10.48	24.9	9:45	50.05	10.54	35.4
4:00	50.03	10.48	24.9	10:00	50.15	10.48	35.5
4:15	49.99	10.48	26.9	10:15	50.05	10.54	31.8
4:30	50.02	10.46	28.9	10:30	50.07	10.47	28.7
4:45	50.01	10.48	25.9	10:45	49.99	10.48	25.3
5:00	50.03	10.48	22.8	11:00	49.99	10.49	22
5:15	50.02	10.48	22.8	11:15	50.9	10.54	22.1
5:30	50.03	10.48	22.8	11:30	49.99	10.50	22.3
5:45	50.00	10.48	22.9	11:45	49.98	10.50	22.4
6:00	50.00	10.48	22.9	12:00	49.98	10.48	22.6
6:15	50.04	10.48	22.9	12:15	50.05	10.46	22.6
6:30	50.01	10.48	23.8	12:30	49.94	10.49	22.6
6:45	49.99	10.48	23.5	12:45	49.94	10.49	22.4