ANALYSYS OF A FUZZY LOGIC POWER SYSTEM STABILIZER FOR STABILITY ENHANCEMENT

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Abstract

Modern power systems consist of several generators working synchronously to meet the power demand. For reliability of these systems, stability must be ensured incase of faults within the system. Faults within a system induce electromechanical oscillations of the electrical generators. These oscillations, also called power swings, must be effectively damped to maintain the system stability. In an attempt to reduce system oscillations, Power System Stabilizers (PSS) are used to add damping by controlling the excitation system. Studies have shown that a well-tuned PSS can effectively improve power system dynamic stability. The paper demonstrates how the Fuzzy Logic Controller can be used to fine tune the PSS and thus improve the overall stability of a power system. Simulations have been carried out on 16 bus test system found in literature. The model was simulated in a MATLAB/SIMULINK environment. A comparison is carried out on a generator without a PSS, with a PSS and with a PSS plus a Fuzzy Logic Controller. The results indicate that the inclusion of a Fuzzy Logic Controller improves the damping of electromechanical oscillations introduced by a three phase fault in the system, and hence improves the overall stability of the system.

Key words: Fuzzy logic, power system stabilizer, stability

1.0 Introduction

Modern power systems consist of several generators working synchronously to meet the power demand. For reliability of these systems, stability must be ensured incase of faults within the system. Faults within a system induce electromechanical oscillations of the electrical generators. (Hadi, 2002).

Power system stabilizers have been developed to aid in damping these oscillations via modulation of the generator excitation. The art and science of applying power system stabilizers (PSS) has been developed over the past 40 to 45 years since the first widespread application to the Western systems of the United States.

To provide damping, the stabilizers must produce a component of electrical torque on the rotor which is in phase with speed variations. The PSS design is based on the linearised model of the power system (Kundur, 1994).

The application of a PSS is to generate a supplementary stabilizing signal, which is applied to the excitation system or control loop of the generating unit to produce a positive damping. The most widely used conventional PSS is the lead-lag PSS. In this PSS the gain settings are fixed at certain value which are determined under particular operating conditions to result in optimal performance for that specific condition. However, they give poor performance under different synchronous generator loading conditions (Gross; 1986).

The parameters of the conventional PSS (CPSS) are determined based on a linearised model of the power system around a nominal operating point where they can provide good performance. Since power systems are highly non-linear systems, 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 operating environment (Sambariya *et al*., 2009). To improve the performance of CPSS, numerous techniques have been proposed for their design, such as using intelligence optimization methods which include simulated annealing, genetic algorithm, Tabu search, fuzzy, neural networks and many other non linear techniques (Sambariya *et al.,* 2009).

This paper proposes to use the Fuzzy Logic Controller in a Multi-machine Power System. Initial studies have been done on the SMIB (Sambariya *et al*., 2009); hence this paper seeks to extend the same to multiple machines operating synchronously. The impact of several controllers is compared under the different faults considered. A comparison is also carried out to compare the impact of the Fuzzy based PSS when the loads are static and dynamic.

2.0 Materials and Methods

The CPSS used in this paper is the Generic Power System Stabilizer (GPSS) simulated in the simulink environment. The GPSS is used to add damping to the rotor oscillations of the synchronous machine by controlling its excitation. The GPSS design is based on the linearised model of the power system (Kundur; 1994)

However the power systems are highly non-linear systems, with configurations and parameters that change with time and the GPSS cannot guarantee its performance in a practical operating environment (Sambariya et al; 2005-2009). Thus the use of a rule-based fuzzy logic controller is recommended. In this paper we compare a rule-based fuzzy logic approach to the common control techniques to a Generic PSS (Kundur; 1994) using the speed deviation $\Delta\omega$ as input, a Generic PSS using the power acceleration P_a as input and a Multiband PSS (Grondin *et al*., 1993).
The fuzzy logic controller can be described by four different parts (El-Hawary1998) which includes: a fuzzification block to transform the input variables to the corresponding linguistic fuzzy variables with their associated membership values; the fuzzy rule base which specifies the control outputs by using linguistic variables and membership functions to determine the degree of truth of input variables; the fuzzy inference represents the human decision making and processes the fuzzy logic operations of the controller and the defuzzification block converts the linguistic output variables back to numeric values used by the excitation system of the synchronous machine to stabilize the power oscillation. The process of designing a fuzzy logic controller can be split up into five different steps (El-Hawary1998).

Firstly, the relevant input variables are chosen. For controlling the excitation of a synchronous machine the relevant variables are the machine speed deviation Δω and the acceleration power P_a which is calculated as follows:

$$P_a = P_m - P_e \qquad \text{……………………………………………………………………………(1)}$$

Secondly, the membership ship functions are defined. A membership function represents the degree of truth of the input signal. For two input signals the degree of truth for each signal is determined and then the maximum of both input signals is taken as the degree of truth. Figure 1 shows the seven set up triangular membership functions for the input variable P_a. A number of 7 linguistic variables are chosen to describe the input and output. For power systems the following linguistic variables have shown to be a good choice: negative big, negative medium, negative small, zero, positive small, positive medium, positive medium and positive big.

Thirdly, a set of fuzzy logic rules has to be implemented. Fuzzy logic rules are expressed as follows:
IF variable IS property THEN action.

To derive the rules one can rely on an off-line simulation as described by (Linkens *et al.,* 1990) or input from experts who are familiar with the system to control. It is also possible to use neural networks which have been trained to generate the rules (Antsaklis, 1990). Every entity in Table 1 represents a fuzzy logic rule. The implemented rules can also be represented in a 3D surface view, (see Figure 2). A set of rules which define the relation between the input and output of fuzzy controller can be found using the available knowledge in the area of designing PSS. These rules are defined using the linguistic variables. The two inputs, speed and acceleration, result in 49 rules for each machine. The rules have the following structure: Rule 1**:** If speed deviation is NM (negative medium) AND acceleration is PS (positive small) then voltage (output of fuzzy PSS) is NS (negative small). Rule 2**:** If speed deviation is NB (negative big) AND acceleration is NB (negative big) then voltage (output of fuzzy PSS) is NB (negative big). Rule 3**:** If speed deviation is PS (positive small) AND acceleration is PS (positive small) then voltage (output of fuzzy PSS) is PS (positive small). And so on….

Following the outputs of the evaluated rules have to be combined to represent a single fuzzy logic set. This is done by aggregating the results of the evaluated rules by using the maximum method. In the final step the aggregated output set is defuzzified to represent a real number which is the output of the fuzzy logic. The most common defuzzifaction method is the cendroid method. It returns the center of an area under a curve (the aggregated output set). Figure 3 shows the matlab/simulink model of the excitation system with the various stabilizers. The output of of fuzzy logic controller is fed via the generic power system stabilizer.

Case Study

For the study a fictitious 16 bus system, Figure 9, from literature was used (Gross; 1986). It consists of nine lines, three generators, and seven load points. The three generators are a steam plant located at Rogers, a hydrogenation plant at Russel Dam and a tie line to an external system connected at Lowry substation. The cities Grigsby, Feasterville, Philipsburg and Honnell represent the major load centers. The hydrogenation plant at Russel Dam and the steam plant at Rogers also take significant loads from the system. The parameters of the system are in Appendix 1. The system was modeled in simulink. This system was stable and could perform load flow and thus formed a perfect platform for introducing a Fuzzy Logic based PSS and assess its impact on the system after various fault. For comparison on the effectiveness of the Fuzzy logic based PSS other stabilizers are analyzed as well. The system was subjected to a three phase fault. Firstly the fault was introduced at bus 3 representing small load and then on bus 7 represeting a large load. The impact of the fault on the mechanical power of the machines was plotted against time under various stabilizers. All the static loads were then replaced with a dynamic load and the output were then compared under the two situations.

The total simulation time was set at two seconds. At this time the oscillations of the mechanical power under a Fuzzy Logic based PSS had reached steady state. The fault was set to occur at 13/60 sec and be cleared at 32/60 seconds. The circuit breaker is set to isolate the fault section at 15/60 and reconnect back the load into the system at 35/60 after the fault has been cleared.

3.0 Results

Figure 5 and 6 shows the output active power of the system simulation under fault conditions when the load at Russel dam and Grigsby are isolated during the fault and reconnected back after the fault. This graphs show the comparison of the various stabilizers used in order to determine which produces the best performance in terms of stability whenever a fault occurs. Figure 7 shows the active power outputs when the loads are dynamic and when the loads are static. The sample of time for the system responses was in five seconds. This is acceptable length of time because at this time, most of the system had achieved desired active power that is 1.0 p.u. The comparison was made by looking at the oscillation and also the time taken by each stabilizer to achieve desired value and maintain stability after system subjected to disturbances.

4.0 Discussion and Conclusion

This study shows that it is possible to stabilize power system whenever a fault occurs within the shortest time possible and therefore making the power system more reliable. The settling time reduced after the system subjected to different disturbances. The desired value of the machine output coming in a very short time compared to the conventional stabilizer. The machine with a Fuzzy Logic based Power System Stabilizer Stabilizer when subjected to disturbances achieved the desired values of active power at 0.8 seconds while the machine with a Multiband Power System Stabilizer (MB PSS)achieved the desired value of active power at 1.8 seconds. The other stabilizer takes a longer period. This meant Fuzzy Logic based Power System Stabilizer Stabilizer achieved the settling time by 55.56% quicker than Multiband Power System Stabilizer Stabilizer.

Fuzzy Logic based power system stabilizer proved to be the most efficient stabilizer in both cases showing that in order to improve the operation of power systems under different fault conditions effective fuzzy controllers should be fitted. This is applicable in sensitive systems which demand consistent supply of power during exchange in the event of power blackout and thus do not have harmful effects on the system operation.

This study shows that Fuzzy PSS is more superior to the other stabilizers. The replacement of the static loads with the dynamic loads does not affect the settling time of the Fuzzy Logic based Power System Stabilizer.

Improvements in this project include the use of Self tuning power system stabilizer based on artificial neural networks which are used to tune the parameters of the PSS during the real time.

Table 2: Fuzzy logic decision table (Antsaklis; 1990)

	Active power							
		NB	NM	NS	Z	PS	PM	PB
Speed deviation	NB	NB	NB	NB	NS	Z	Z	PS
	NM	NB	NB	NM	NS	Z	PS	PM
	NS	NB	NB	NM	Z	PS	PM	PB
	Z	NB	NM	NS	Z	PS	PM	PB
	PS	NB	NM	NS	Z	PM	PB	PB
	PM	NM	NS	Z	PS	PM	PB	PB
	PB	NS	ZR	ZR	PS	PB	PB	PB

Table 2: System load data

Bus	P (MW)	Q (Mvar)
1	-	-
2	0	0
3	10	55
4	0	0
5	75	15
6	0	0
7	90	20
8	0	0
9	15	4
10	0	0
11	0	0
12	0	0
13	50	2
14	35	3
15	0	0
16	150	20

Table 3: System generator data

Bus	S_r (MVA)	V_{Lr} (kV)	P_G (MW)	Q_{max} (Mvar)	Q_{min} (Mvar)
1	-	345	-	-	-
3	120	13.8	110	80	-40
9	250	13.8	220	140	-100

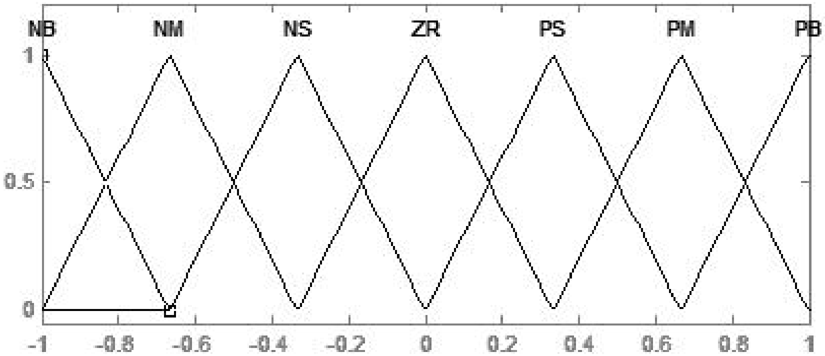

Figure 11: Membership functions for input Pa

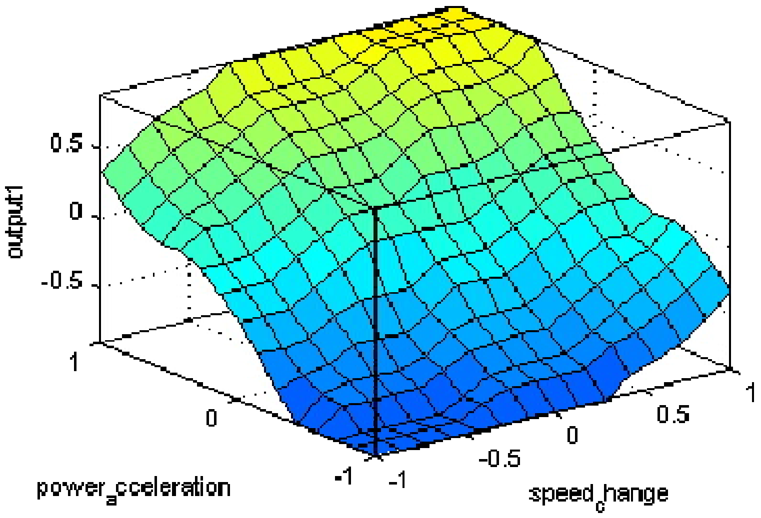

Figure 2: Surface view of fuzzy logic rules

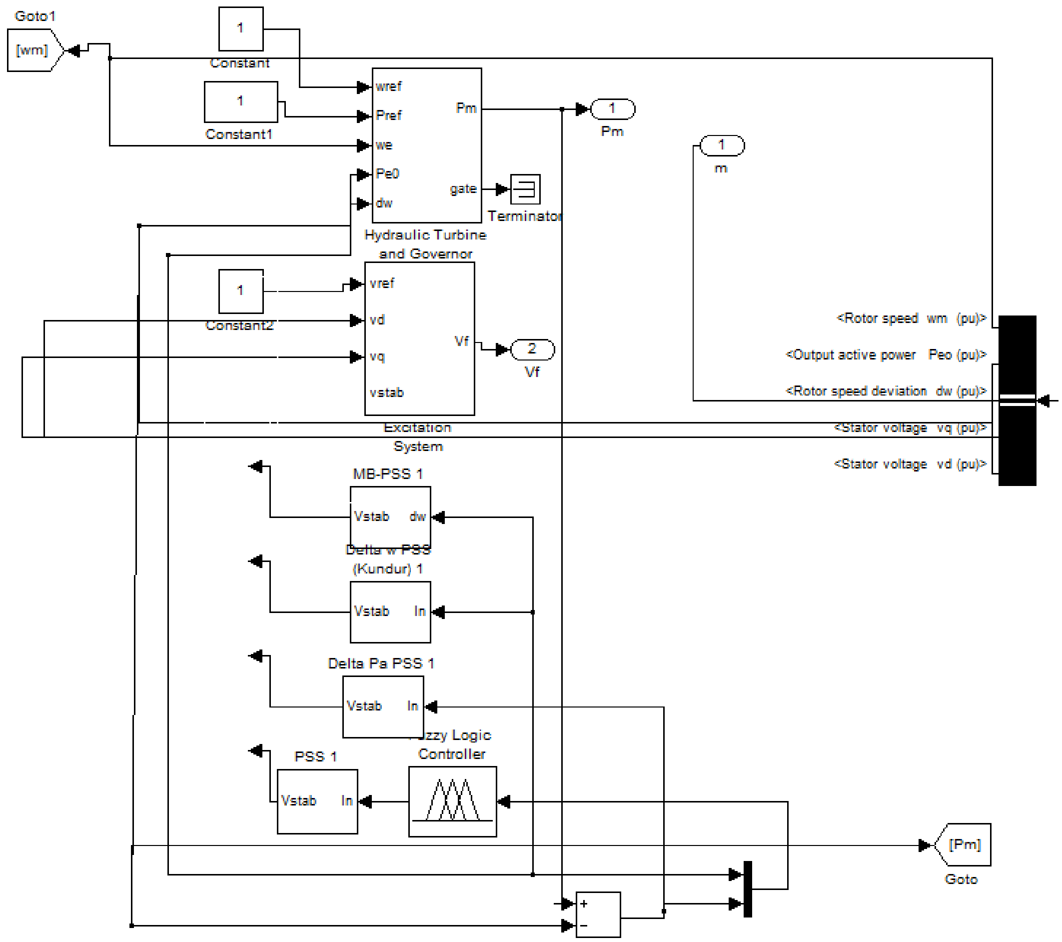

Figure 3: Matlab model of the machines excitation system with 4 power system stabilizers

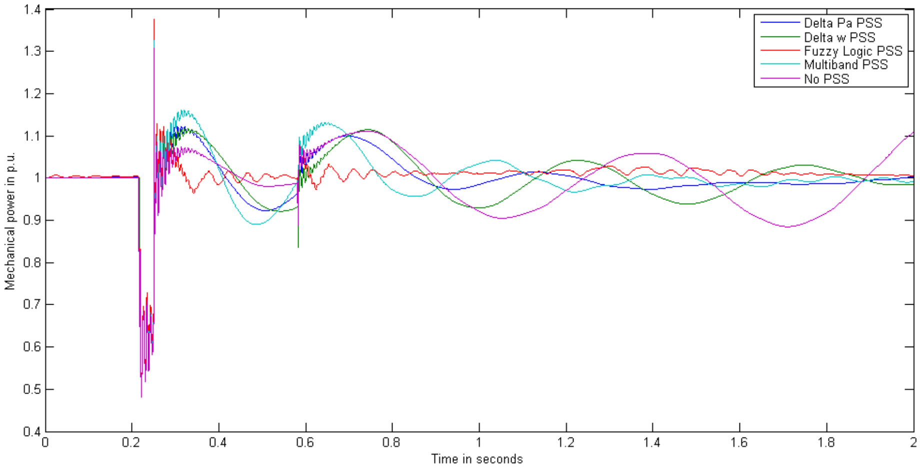

Figure 4: Response of various controllers due to a fault at the 10MW, 55Mvar load at Russel Dam

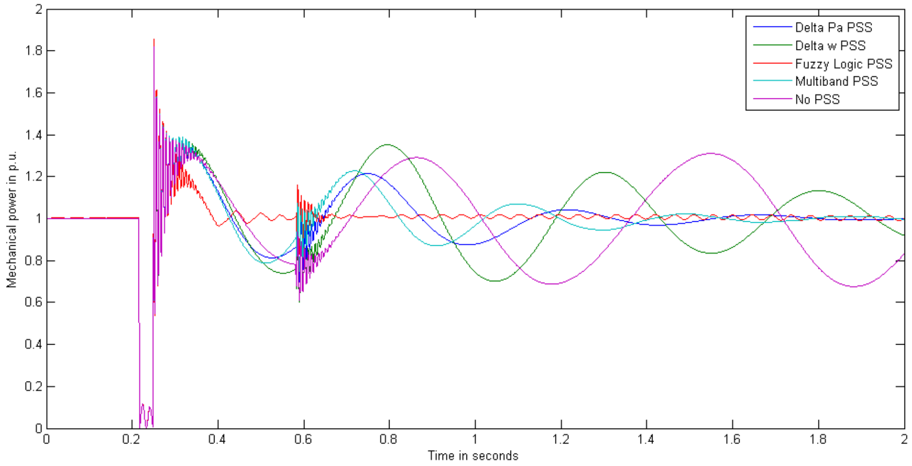

Figure 5: Response of various controllers due to a fault at the 90MW, 20 Mvar load at S. Grisby Substation

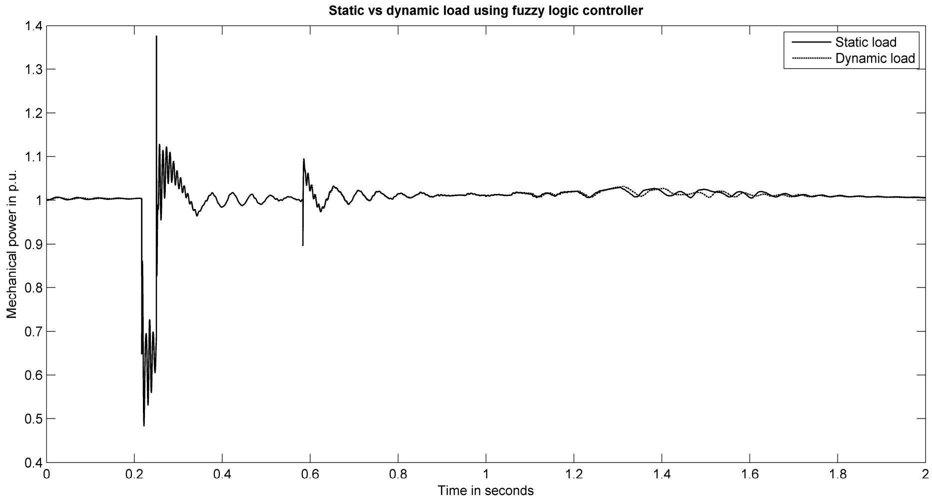

Figure 6: Response of Fuzzy PSS controllers when the 10MW, 55MVar load is static and dynamic

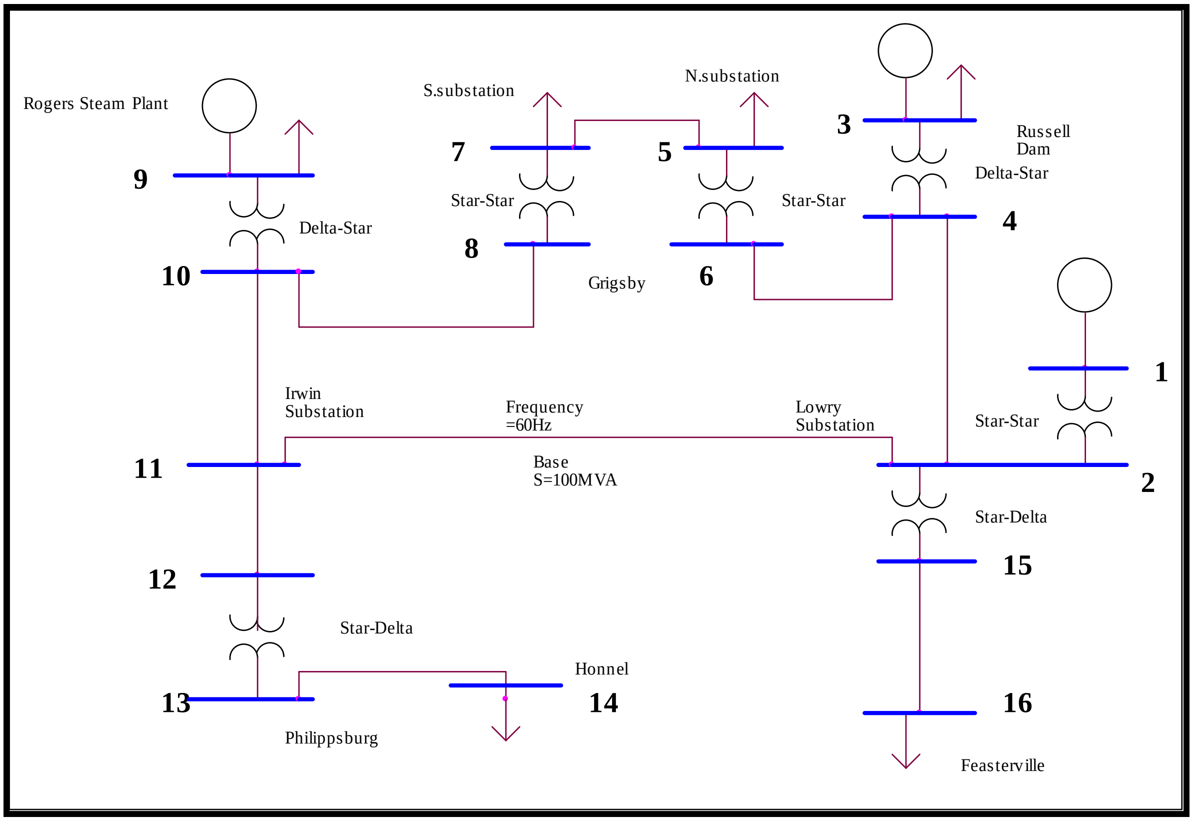

Figure 7: Single line diagram of the 16-bus model

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Appendix 1

Transmission Line Parameters

R1= 0.01273 Ohms/km, R0=0.3864 Ohms/km
L1=0.9337 mH/km, L0=4.1264 mH/km
C1=12.74 nF/km, C0=7.751 nF/km
Line length: 156km

Base Voltage Specifications

345kV	Bus 1
230kV	Bus 2, 4, 6, 8, 10, 11 and 12
115kV	Bus 5, 7, 15, 16
69kV	Bus 13, 14
13.8kV	Bus