ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

Modelling of Adıgüzel Hydroelectric Power Plants for Short Circuit Analysis in the Transmission Network

Yüksel Oğuz[1], Ahmet Kaysal[2]

Associate Professor, Dept. of Electrical & Electronics Engineering, Afyon Kocatepe University, Turkey[1]

Research Assistant, Dept. of Electronic & Automation, Afyon Kocatepe University, Turkey[2]

ABSTRACT: In this study, dynamic behaviour modelling of Adıgüzel hydroelectric power plant (HEPP) is executed by implementing Matlab/Simulink software program to carry out the short circuit analysis in case of various charging of electricity loads. By building a system to reflect the behaviour of real feature under the control of the governor and using both classic (PID) and self-adjustable fuzzy logic control system (FLC) performances of 36MVA powered synchronous generator and dynamic model of the other components in the system were studied in case of short circuit faults of the possible phase-earth, phase-phase, two phase and three phase earth. It is observed that in the simulation studies which were carried out the fuzzy logic control system became stable in a short period of time, within the limits of allowed tolerance when both control systems compared.

KEYWORDS: Hydroelectric Power Plant, Short Circuit Analysis, Fuzzy Logic Controller

I.INTRODUCTION

Electric power is indispensable for the modern world. An irregularity in electrical energy supplies adversely affects our quality of life and causes economic losses for the industry as well. For these reasons it is very important to reach consumers the uninterrupted electric energy supply on a regular basis. To achieve this, it is requisite to analyse all potential malfunctions in transmission lines and during production with all known methods.

When two or more conductors contact with earth or with each other a fault occurs [1]. This failure, which we refer as the short circuit occurs because insulation feature of the insulating material is lost. Deterioration of insulation can be due to a result of aging, overvoltage breakdown, misuse of the material, and this also can be caused by factors such as mechanical failure. In the case of a short circuit the overall impedance of the circuit is reduced therefore current in the branches of the circuit increases. Because the currents increase voltage in the circuit elements drops; hence the voltage values in the various nodes decreases as well.

Three-phase systems failures are classified as follows:

(i) Single phase – ground failures.
(ii) Phase – phase failures.
(iii) Two phases – ground failures.
(iv) Symmetrical three phase failures.

Earth failures compose of more than 80% of all faults and are considered to be one of the fundamental problems in power system [2]. The importance of the short circuit problem and requirement of a fast reaction of the present systems to these failure problems as quickly as possible are the main reasons why many studies have been made.

Ekici and his colleagues analysed the simulation of short circuit current and voltage signals obtained from wavelet packet transform (WPT) and used method artificial neural networks (ANN) to locate failure [3]. Oğuz and Demirören designed the fuzzy logic-based automatic voltage regulator circuit, to enhance damping of the oscillation of the temporary period in a single area consisting of a power system and it is observed that during and after three phase symmetrical short circuit the fuzzy logic based controller proved that amplitude of oscillation of drops and the amount

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

of time to settle is shortened when compared to those of classic controller [4]. Similarly in their study Zhao and Feng created mathematical models in the model of dq coordinate system in a 1000MW power synchronous generator and examined analysis of three phase short circuit fault. Simulation charts have shown synchronous generators suffer a volatile phase during the huge impact of a sudden short circuit and when short circuit surge is over, they reach a stable level [5]. In their study Barakat and his colleagues created a dynamic model of 75 kVA synchronous generator carried out sudden short circuit and open circuit simulations and, according to the results of their simulation the terminal of the damping core has no impact on the behaviour of the machine [6]. In their study, Jing and his colleagues, created dynamic model with the Lorentz force method and read the electromagnetic measures of a 1000 MW powered salient pole synchronous generator and when three-phase short circuit fault occurred, went through the state of electromagnetic waves in windings and simulation graphics [7]. In their study, Sulla and his colleagues used the Crowbar method in which the rotor current is high or exceeds the value in the limit cases of the link voltage, the generator rotor power electronics keys are short circuited via external resistors, and they presented a generic method for squirrel cage (SCIG) and DFIG calculation of short circuit current of the generator [8]. Howard and his friends proposed a new model of short circuit for double fed induction generator (DFIGs) rotor-side conversion (RSC) and generator-side conversion (GSC) under control of balanced malfunctions. [9]. In their study, Shafaie and Kalantar studied performance of 10 MW wind turbine of the high temperature superconductor (HTS) dq which is an equivalent circuit model of three phase sudden short circuit failure by creating the required conditions of the finite element method [10]. In their study, Aubert and his colleagues made their model based on permanent-magnet synchronous generator (PMSGs) built as dq model by creating short circuit values associated with the breakdown and estimated the EKF algorithm (Kalman filtering) on the basis of prediction. Additionally, they made a comparison of the results with their experimental work by gradually short circuiting the stator winding [11]. Hu Jiawu of China carried out his experiment in a gigantic hydroelectric power plant and came up with a detailed analysis of symmetric components method for the short circuit failure and the cause of the malfunction in the hydro-generator terminal [12].

In this study two types of controllers were also designed, effects of PID and FLC on the system were studied. Analysis of the quality of power which is derived from Adıgüzel hydroelectric power plant and replacement of a newly designed controller to enhance the performance of current production system and the applicability of new controllers and reaction of these new controllers against short circuit have been done in this study.

II.MATERIAL AND METHODS

As a result of a short circuit the increase in the electric current is dangerous for the circuit elements and the voltage reduction has adverse impact on the work of its consumers. In the case of working with the lower voltage the electrical devices and their components deviate from the normal behaviour. The main types of short circuits and probability of their occurrence are as follows [13].

(i) 3 phase (1% – 7)
(ii) 2 phase (2% – 13)
(iii) 2 phase – ground (5% – 20)
(iv) 1 phase – ground (60% – 92)

In Fig 1 the given short circuit current reaches to a maximum peak value and this current, firstly fast and then petering out quickly to a permanent stable short circuit current. For a short period of time the current becomes asymmetrical to the horizontal axis. If the short circuit failure occurs in a faraway point from the generator, generator impedance loses its effects when compared to grid impedance. The initial value of the short circuit current is slightly different from the value of the stable short circuit current [14].

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

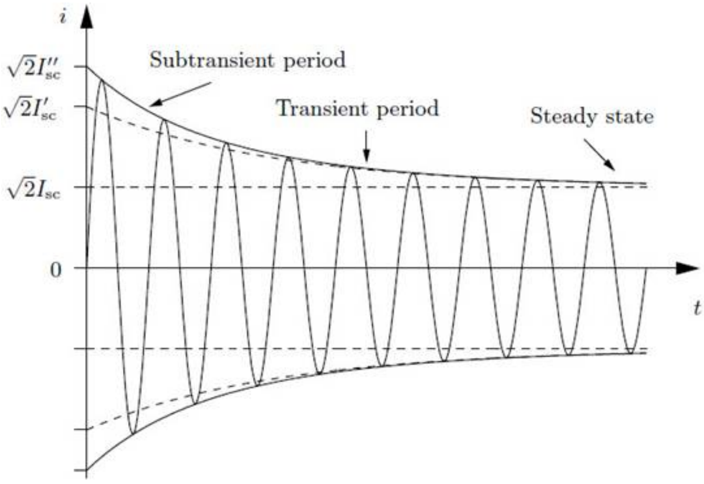

Fig.1. Symmetrical short circuit armature current in synchronous machine

Linear models of Network elements and linear equations of a system in any shape for a short circuit i node point can be represented in a network model, such as in Fig 2.

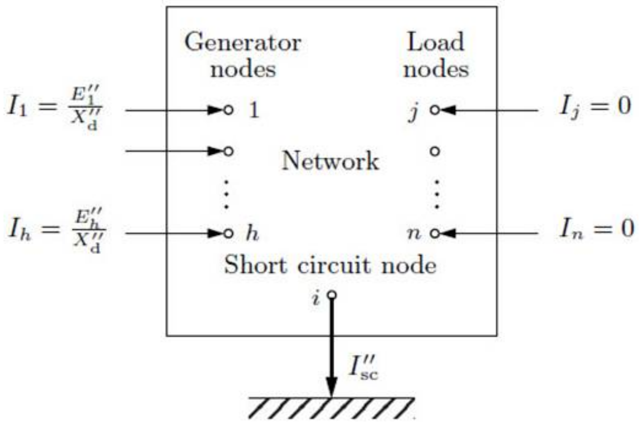

Fig.2. Network with short circuit at node i [15]

To calculate i node at I_{sc}'' the short circuit equality (1), (2) and (3) can be written [15].

$$Y.U = I \quad \textbf{(1)}$$

Here

- Y, node admittance matrix
- U, node voltage vector
- I, current vector

$$U = \begin{cases} U_j & if\ j \neq i \\ 0 & if\ j = i \end{cases} \quad \textbf{(2)}$$

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

$$I = \begin{cases} \dfrac{E_j}{X''_{dj}} & for\ generator\ nodes\ j \neq i \\ 0 & for\ load\ nodes\ j \neq i \\ -I''_{sc} & for\ short\ circuit\ node\ without\ generation\ j = i \\ -I''_{sc} + \dfrac{E_j}{X''_{dj}} & for\ short\ circuit\ node\ with\ generation\ j = i \end{cases} \quad (3)$$

In this study, the simulation performance of the equipment technical data obtained is provided in Table 1, Table 2 and Table 3.

Table 1**.**Synchronous generator parameter [16]

Type		A.C. synchronous generator, vertical shaft
Rotor type		Salient pole
Nominal power		36 MVA
Rated power factor		0.85
Rated frequency		50 Hz
Rated voltage		13.8 kV
Rated current		1506 A
Rated speed		300 rpm
Runaway speed		630 rpm
Stator winding resistance		0.0141 Ω
Rotor winding resistance		0.0857 Ω
Rotor pole pairs		10
Stator winding connection		Star
Reactance based on rated load and rated voltage (pu)	X_d	0.992
	$X_d{}'$	0.295
	$X_d{}''$	0.183
	X_Q	0.687
	$X_Q{}''$	0.186
	X_l	0.184
Time constants	$T_{do}{}'$	7.133 s.
	$T_d{}'$	2.123 s.
	T_a	0.177 s.

Table 2.Hydraulic turbine and governor [16]

Type		Vertical shaft Francis
Effective head	Max.	132.80 m.
	Nor.	116.00 m.
	Min.	84.30 m.
Output at normal head		31.375 kW
Discharge at normal head		30 m^3/s
Revolving speed		300 rpm
Water starting time (T_W)		1.4047 s
Permanent droop		0.05
Servo gain (K_a)		3.3
Servo time constant (T_a)		0.07 s

Table 3. Three phase transformer parameters [16]

Nominal Power		36 MVA
Rated frequency		50 Hz
Winding 1 parameters (ABC terminals)	Connection	D11
	Rated voltage	13.8 kV
	Rated current	1506 A
	Resistance	0.0178 Ω
	Inductance	0.00174 H
Winding 2 parameters (abc terminals)	Rated voltage	154 kV
	Rated current	135 A
	Resistance	1.5056 Ω
	Inductance	0.2172 H

III. ADIGÜZEL HEPP SHORT CIRCUIT MODEL AND FUZZY LOGIC CONTROLLER DESIGN

The stator terminal voltage, the stator current and synchronous generator's excitation voltage of the possible failures as the phase-earth, two phase-ground, two-phase, three-phase short circuit ground-contact and non-contact failures of power systems in the simulation designed circuit provided us with the graphics, the results were compared with the actual breakdown of these malfunctions, the end product simulations were commented. The power generation system block diagram of Adıgüzel HEPP simulation is given in Fig 3. This diagram consists of power generation system, hydraulic turbine and governor, excitation regulator, salient pole synchronous generator, power transformer, load,

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

wattmeter, frequency meter and bars. Three-phase short circuit block's diagram was added to the system output. The oscilloscope that shows electrical quantities provided us with all the consumer power, system frequency, the terminal voltage and load current signals analysis of the output system.

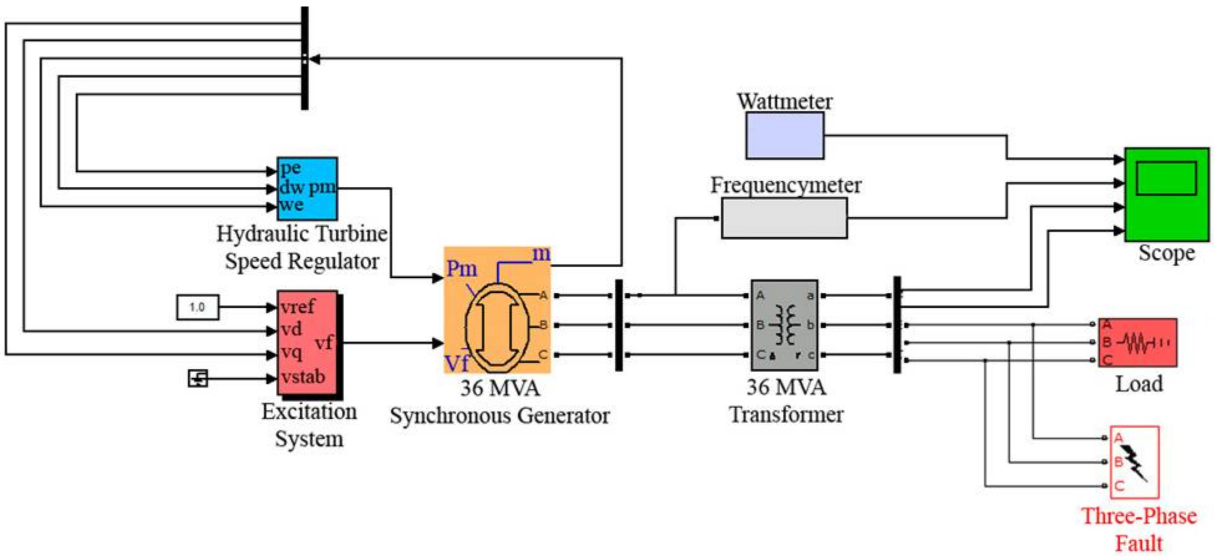

Fig.3. Power generation system with a short circuit block diagram addition.

Sub-simulation block diagram consisting of servo-motors, hydraulic turbines, PID and FLC in Fig 4.

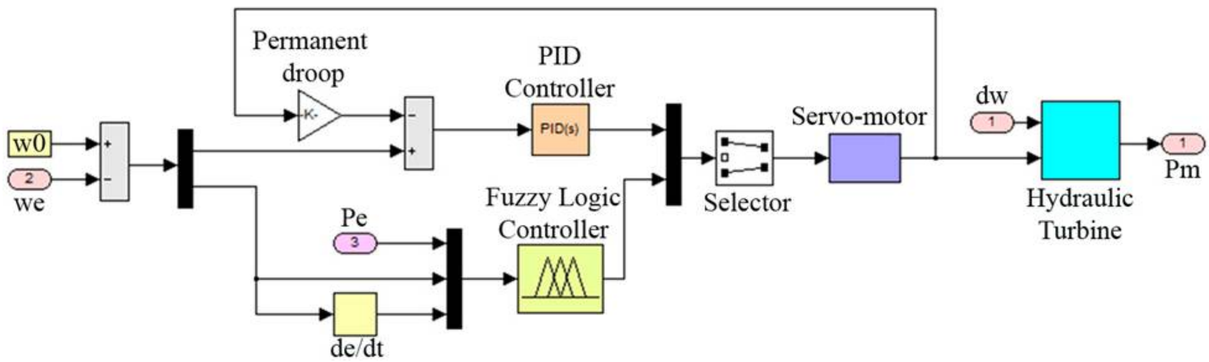

Fig.4. Sub-simulation block diagram of the hydraulic turbine.

PID controller and FLC as a secondary controller were used in Adıgüzel HEPP's governor circuit design. The performance of the system, the settling time of the next frequency after any disruptive impact like a short circuit and the system's response time were seen to have better results than the designed PID controller in the simulation.

To improve the working performance of the power generation system and to obtain the desired quality power, the FLC based on sugeno fuzzy inference system was designed. The three input signals to the controller are as the first; the error signal$e(t)$, the second; changes according to the time of the error signal $de(t)/dt$, and final one the third; HEPP output power drawn from the output and calculated as per-unit $pe(t)$ value. The output signal of the controller is the $u(t)$control signal which controls the servo motor to adjust setting of a wingspan to the desired extent. Three input variables of the fuzzy logic controller block diagram designed in the system is given in Fig 5.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

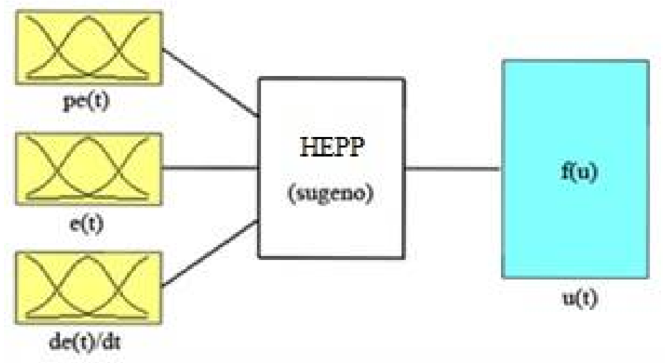

Fig.5. Block diagram of the fuzzy logic controllers used in the system.

The error signal e(t)of FLC's input variables and linguistic variables of change signal in the errorde(t)/dt 's, negative with (N), zero with (S) and positive with (P) are shown. The third input variable, which is drawn from the power bus signalpe(t) 's linguistic variables are positive small (PK), positive medium (PO) and positive big (PB) type. Inputs of fuzzy inference systems, triangle type of membership functions with ranges of values are also shown in Fig 6. While creating the rule base from the logical operations "and" operator is picked to use.

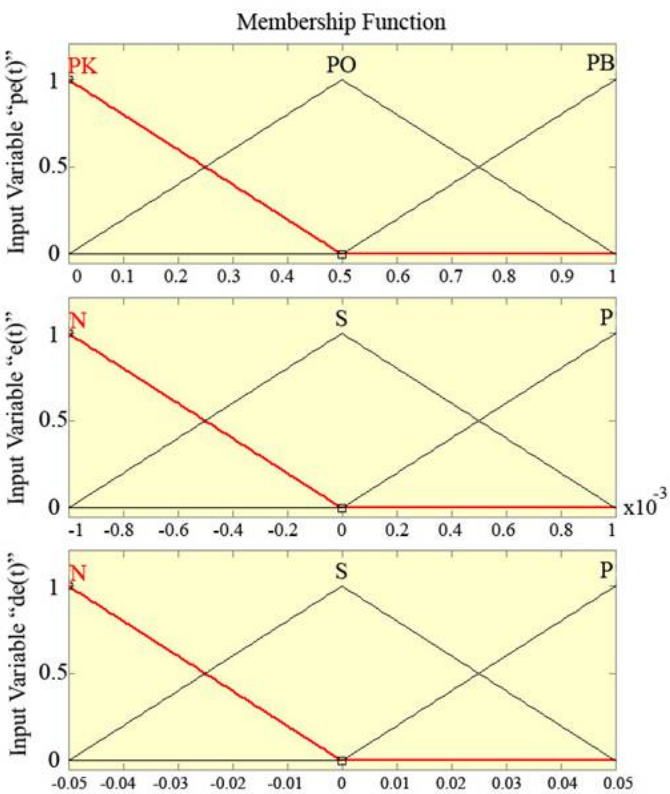

Fig.6. Membership functions and ranges

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

IV. ADIGÜZEL HEPP SHORT CIRCUIT SIMULATION RESULTS AND DISCUSSION

The control system of Adıgüzel HEPP electro-hydraulic governor was examined and PID and FLC were designed to improve the response time that the system's voltage and frequency changes and to minimize the oscillation in the system soon and simulation studies were performed. All the simulations made at 154kV bus, 5 s after the simulation began, a short circuit occurred and after 5.1 s the short circuit disappeared. Simulations lasted only 120 s but periods of 15 s time were added as the simulation graphics.

A. Simulation of Phase-Ground Fault

In Fig 7 for phase-to-ground fault condition related simulation results, the synchronous generator output current, terminal voltage, synchronous generator excitation voltage and speed were examined thoroughly. In case of failure nominal effective value of the stator terminal voltage being $13{,}8kV$ turned into $V_{ef} = 10{,}96kV(V_{max} = 15{,}5kV)$at the moment the short circuit occurred but after eliminating short circuit and reached levels of $V_{ef} = 15{,}10kV(V_{max} = 21{,}35kV)$when a steady state of the system was obtained, it arose to the level of the nominal value of the terminal voltage. The stator current with a nominal effective value being$1506A$, when the short circuit occurred at the impact short-circuit current read as $I_{ef} = 3260A(I_{max} = 4610A)$and continuous short-circuit current read as$I_{ef} = 3220A$. Excitation voltage reached to the maximum value of 11.5 pu when the short circuit occurred and made oscillations in a short period of 6 seconds and died away. The nominal value of synchronous generator with a speed value of 300 rpm dropped to 297 rpm at the moment of short circuit. 40 seconds after the failure its condition became stable by making oscillations. As a result of the simulation, in faulted phase, as expected, the voltage dropped and current was recorded to rise.

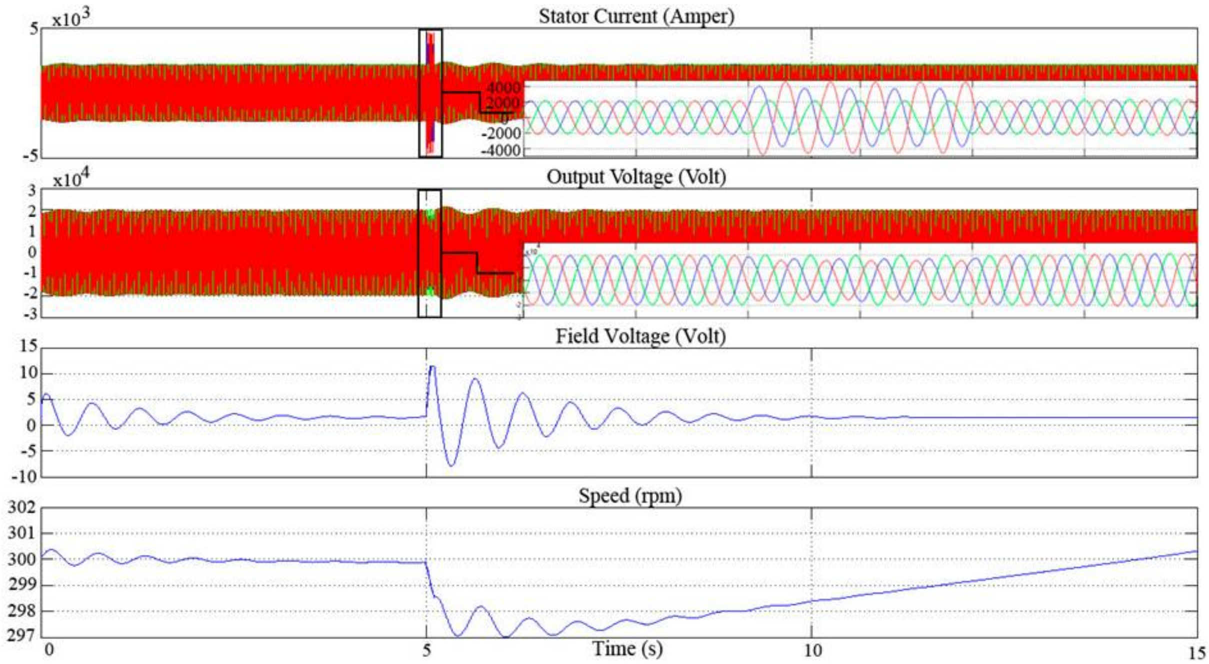

Fig.7. Electrical output magnitudes when the phase-to-ground fault occurs

B. Three-phase symmetrical fault simulation

In the symmetrical three-phase short circuit failure in Fig 8, stator terminal voltages read as $V_{ef} = 5{,}042kV$ $(V_{max} = 7{,}13kV)$in the phases where the short circuit occurred so this meant a decrease by 63,46 percent. After eliminating the short circuit it raised to the levels of $V_{ef} = 16{,}15kV$ $(V_{max} = 22{,}84kV)$. Within 3-4 seconds it reached the nominal value of the terminal voltage. The impact at the moment of occurrence of a short circuit read as short-circuit current

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

valueI_{ef} = 8733A(I_{max} = 12,35kA). When short-circuit occurred, excitation voltage reached the maximum value 11.5 pu per value, and this value was limited. The excitation system similar to other short-circuit fault conditions gained a stability in a short period of time such as 6-7 seconds. Synchronous generator speed climbed to 304 rpm in a short time in case of the short circuit and after simulation started in about 55-60 seconds, died away by making oscillations. The result of the simulation proved to be as expected and in the faulty phases voltage and current remained between their equal amplitude and maintained the 120° phase difference.

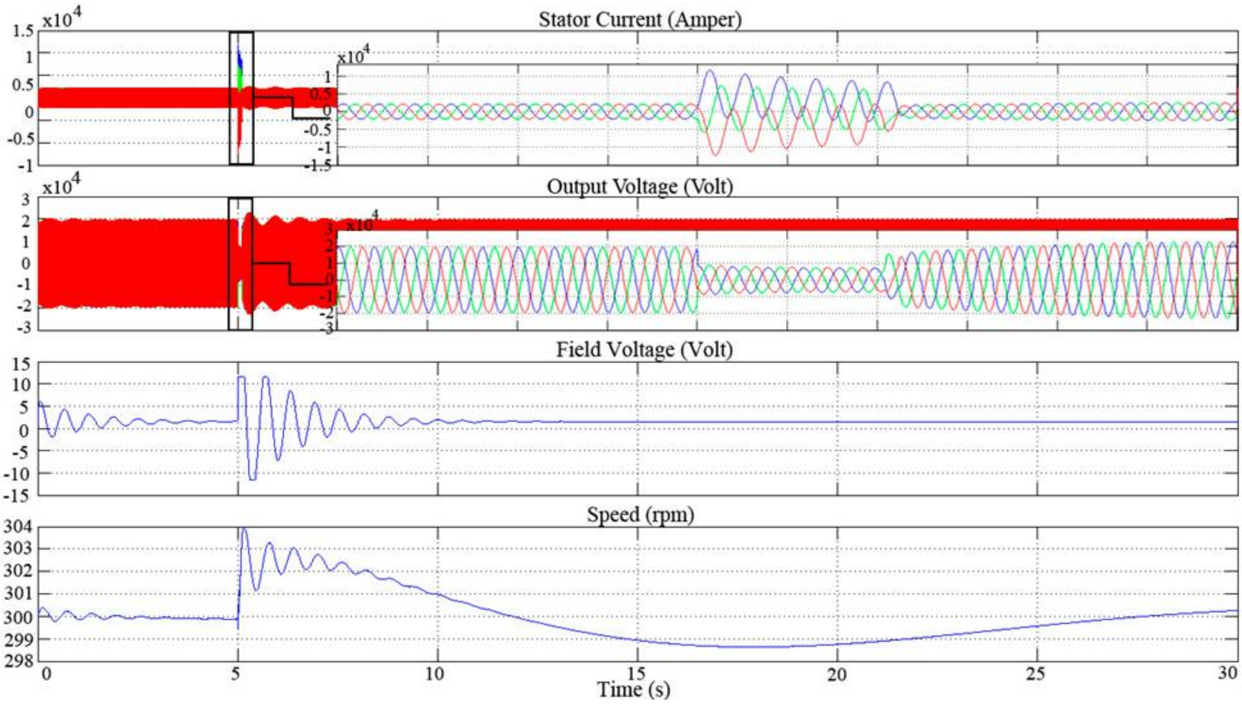

Fig.8. Electrical output sizes when the symmetrical three-phase fault occurs

To set an example three-phase symmetrical fault simulation was also performed at 13,8kV bus. Simulation results related to fault conditions are also shown in Fig 9. In the event of failure, the stator terminal voltage neared to zero in the phases where short-circuit occurred and after the short circuit was eliminated it reached to the levels ofV_{ef} = 16,31kV (V_{max} = 23,07kV)in 3-4 seconds, which is the nominal value of the terminal voltage. When short-circuit occurred the impact of the short-circuit current read asI_{ef} = 15,91kA (I_{max} = 22,5kA). Excitation voltage and synchronous speed were as they were in the other three phase symmetrical short circuit. As it was stated in the generator technical catalogue [16] that Adıgüzel HEPP synchronous generator had the specified three-phase short-circuit which is22kA and the current value of the simulation overlapped simulation value of 22,5kA that was performed in three phase symmetrical short circuit.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

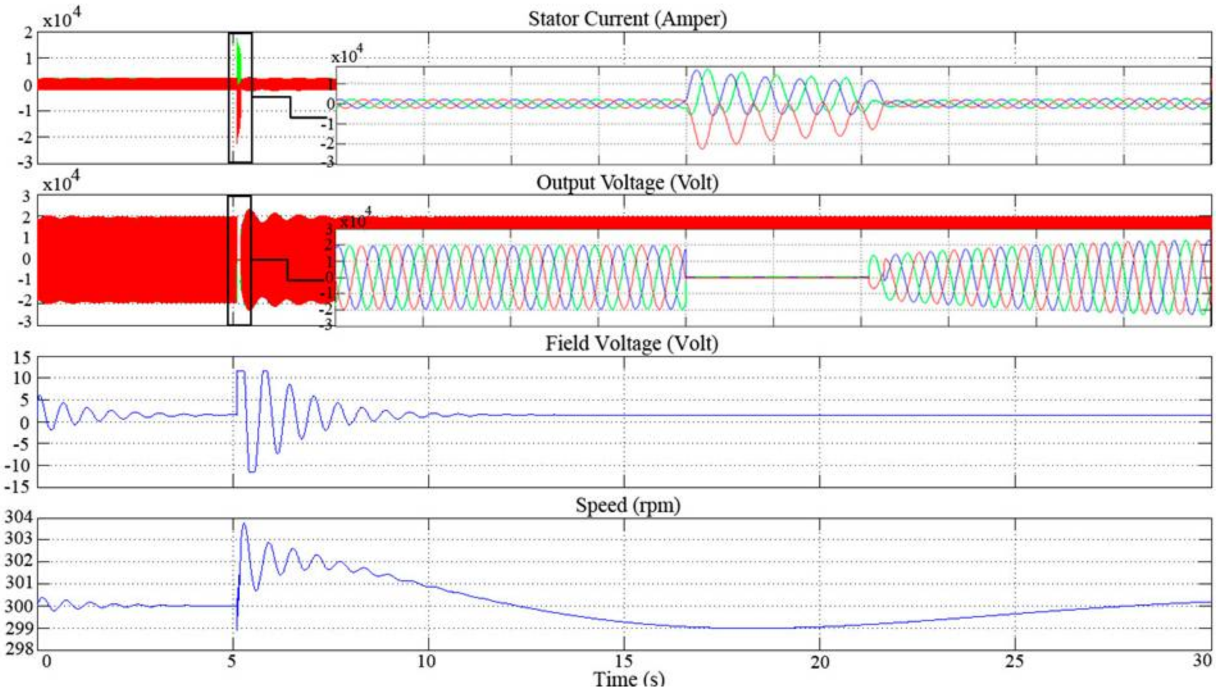

Fig.9. Electrical output sizes at 13.8 kV bus when the failure occurred at the three-phase symmetrically

According to the results of data obtained from the short-circuit failure occurrence during the performed simulation, the value of voltage and current at the moment when the short circuit occurred and a comparison of these parameters with the nominal current are given in Table 4.

Table 4. Short Circuit Data for the 154 KV Network

	Ik" (sub transient short circuit current – peak value)	Vk" (short-circuit voltage – peak value)	Percentage of rated currentpeak value (2130 A)
Single-phase to ground fault	4,61 kA	15,5 kV	216%
Phase to phase fault	11,7 kA	10,15 kV	549%
Two phase to ground fault	12 kA	9,35 kV	563%
Three-phase fault	12,35 kA	7,13 kV	580%
Three-phase to ground fault	12,35 kA	7,12 kV	580%
Three-phase fault (13,8 kV bus)	22,5 kA	$\cong 0$	1056%

C. In cases of Failure the Impact of the Controllers on of Synchronous Speed

Our study was carried out to evaluate the response of PID and FLC controllers in the governor on a synchronous speed when a symmetrical three phase fault occurred. The PID and FLC simulation results are given in Fig 10.

At the time of symmetrical three-phase short, while PID was keeping synchronous generator at a speed of $303\ rpm$, FLC synchronous generator remained at $301{,}5\ rpm$ levels. According to FLC, PID controller system was seen to have much more time in speed oscillation and gaining stability.

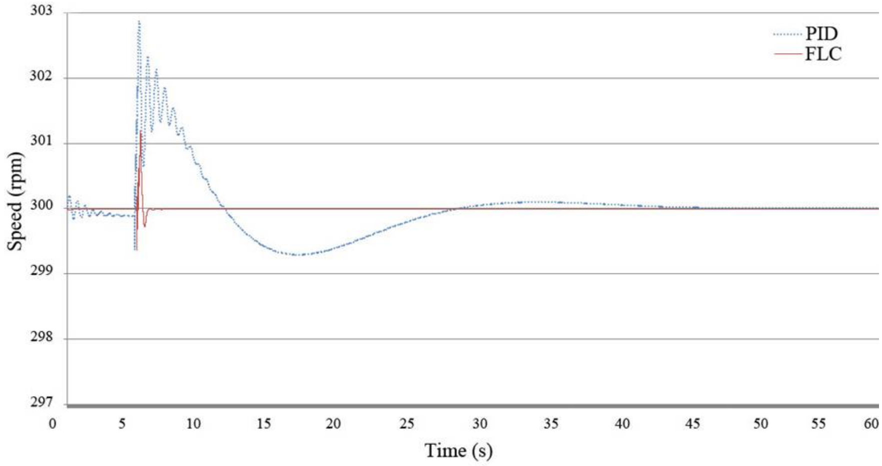

Fig.10. The response of the PID and FLC controllers to three-phase short circuit

V.CONCLUSION

To avoid time consuming calculations in power system worked out mentally and to minimize the miscalculation mistakes it is more advantageous to carry out the short circuit analysis with Simulink modelling. It also helps to study the short circuit event depending on time. On the designed simulation circuit, it is possible to analyse different values and controllers by easily changing parameters of the equipment.

Failure analysis of the symmetrical three-phase short circuit done at Adıgüzel HEPP simulation circuit yielded the impact of short circuit current value which almost matched the true short circuit current value specified in the synchronous generator technical manual [16]. According to the simulation results, and based on their performance outcome on systems, the designed controllers will be easy to adapt to the existing systems.

REFERENCES

[1] M. E. Hawary, Electrical power systems IEEE press,pp. 469–536, 1995.
[2] A. Tungkanawanich, Z. Kawasaki, K. Matsuura, and H. Kuno, "Ground fault discrimination based on wavelet transform using artificial neural networks", Transactions of The Institute of Electrical Engineers of Japan, Vol.120, Issue 10, pp. 1263–1270, 2000.
[3] S. Ekici, S. Yıldırım, and M. Poyraz, "Energy and entropy-based feature extraction for locating fault on transmission lines by using neural network and wavelet packet decomposition",Expert Systems with Applications, Vol.34, Issue 4, pp. 2937-2944, 2008.
[4] G. Oğuz, A. Demirören, "Improving transient stability of power systems with fuzzy logic controller," Electrical, Electronics and Computer Engineering Symposium, Bursa, pp. 1-5, 2004.
[5] L. Zhao, Y. Feng, "Simulation and analysis of short circuit in 1000MW synchronous generator based on simulink/SPS module", Asia-Pacific Power and Energy Engineering Conference, pp. 1-4, 2010.
[6] A. Barakat, S. Tnani, G. Champenois, and E. Mouni, "Analysis of synchronous machine modelling for simulation and industrial applications", Simulation Modelling Practice and Theory,Vol.18, Issue 9, 1382-1396, 2010.
[7] C. Jing, L. Yan-ping, and Y. Qing-shuang, "The electromagnetic force calculation of damping windings under three-phase sudden short-circuit fault of large hydro-generator", The 6th International Forum on Strategic Technology, pp. 533-536, 2011.
[8] F. Sulla, J. Svensson, and O. Samuelsson, "Symmetrical and unsymmetrical short-circuit current of squirrel-cage and doubly-fed induction generators", Electric Power Systems Research,Vol.81, Issue 7, 1610-1618, 2011.
[9] Dustin F. Howard,Jiaqi Liang and Ronald G. Harley, "Short-Circuit Modelling of DFIGs With Uninterrupted Control", IEEE Journal of Emerging and Selected Topics in Power Electronics, Vol.2, Issue 1, pp. 47 – 57, 2014.
[10] RouhollahShafaie, Mohsen Kalantar, "Transient performance of a large scale wind turbine HTS synchronous generator under short circuit conditions", Thermal Power Plants (CTPP), pp. 99 – 102, 2014.
[11] Brice Aubert, JérémiRégnier, StéphaneCaux, and Dominique Alejo, "Kalman-Filter-Based Indicator for Online Interturn Short Circuits Detection in Permanent-Magnet Synchronous Generators", IEEE Transactions on Industrial Electronics, Vol. 62, Issue 3, pp. 1921 – 1930, 2015.
[12] Hu Jiawu, "Analysis of and reflection on the short-circuit fault of a large hydraulic generator", IET Generation, Transmission & Distribution, Vol. 8, Issue 4, pp. 661 – 669, 2014.
[13] N. Şerifoğlu, and O. Soysal, Electricity Energy Systems, Papatya publishing, 2. Edition, İstanbul, 2006.
[14] V. Doğruer, "Short circuit fault analysis with matlabsimulink in electrical power systems and the study of Van energy transmission line as an example", M. Sc. Thesis, YüzüncüYıl University, Van, 2007.
[15] GöranAndersson, Modelling and Analysis of Electric Power Systems. EEH - Power Systems Lab., 2008.
[16] Anonymous, Adıgüzel DAM and hydroelectric power plant technical specifications-generators, The State Hydraulic Works, Ankara, 1983.