**Javed A. LAGHARI [1, 3], Hazlie MOKHLIS[1, 2], A. H. A. BAKAR[2], M. KARIMI[1, 2], H. MOHAMMAD[2,4]**

Department of Electrical Engineering,University of Malaya (1), UM Power Energy Dedicated Advanced Centre (UMPEDAC)(2),
Quaid-e-Awam University of Engineering Science & Technology, Pakistan(3),
Faculty of Electrical Engineering, University of Technology MARA, Malaysia (4)

# Comparison of Fuzzy and PID Based Governor's Response in Utilization of DG Spinning Reserve

***Abstract**. When tripping events or overloading cases occur in power system, load shedding scheme operates to shed some load and stabilize the frequency. However, amount of load to be shed greatly depends on, how fast governor can utilizeDG spinning reserve. This paper compares the response of DG with fuzzy based governor and PID based governor in utilization of DG spinning reserve. The simulation results show that DG with fuzzy based governor utilizes spinning reserve more quickly and requires lesser load to be shed than a DG with PID based governor.*

***Streszczenie.** W artykule przedstawiono porównanie dwóch metod kontroli systemu elektroenergetycznego (źródeł rozproszonych). Jedna wykorzystuje logikę rozmytą, a druga regulator PID. Kryterium porównawczym jest efektywność wykorzystania rezerwy mocy przy danym obciążeniu. Przedstawiono wyniki symulacyjne badania. (**Metody zarządzania energią generatorów rozproszonych w zagadnieniu wykorzystania rezerwy – porównanie logiki rozmytej i regulatora PID**).*

**Keywords:** Mini hydro, Fuzzy based governor, PID based governor, Under-Frequency Load Shedding (UFLS) Scheme
**Słowa kluczowe:** zarządca, logika rozmyta, regulator PID, schemat UFLS.

## Introduction

Distributed generation (DG) refers to small type of electric power generation having capacity less than 10 MW [1]. Distributed Generation (DG) penetration in power system network has been widely employed due to market deregulations and environmental issues. However, its increasing penetration has opened the new challenging issues in the field of power system. DG penetration has the advantage that it increased the reliability and efficiency of power system[2]. However, DG penetration in existing power system has caused various problem and power system need to be modified. One of the modifications is operation of DG in islanded mode, a case in which DG is electrically isolated from main grid. This causes DG tripping or over loading incidents in power systemdue to imbalance between generation and load demand.

There are two approaches to control the frequency. During normal operation of DG based Mini hydro, the frequency is maintained by controlling turbine speed [3]. Commonly, Governor is applied for frequency control. However, for system failure or overloading cases, load shedding technique is applied to control the frequency within acceptable range.

The governor's response plays an important role in frequency control during normal operation as well as system failures or over loading cases. When power system network is subjected to DG tripping or overloading events, load shedding scheme start to operate to stabilize the frequency by shedding some load. The amount of load to be shed to stabilize the system frequency varies directly with governor's response in utilization of its DG spinning reserve.If governor utilizes DG spinning reserve quickly, the amount of load to be shed will be smaller and vice versa. In the past, mechanical hydraulic governor were applied for this purpose. Mechanical hydraulic governor due to its slow response is not suitable for today's complex power system involving sharing of distributed generation. Alternatively, electro-hydraulic PI/PID governor are used for frequency regulation. PID controllers best deals with linear models and basic of PID controller are explained in [4,5]. Furthermore, PID controllers may fail in controlling complex and non-linear systems due to un-optimum P, I, D parameter setting and have severe problem of integrator wind-up [6,7]. Hence, an intelligent controller that can be easily used and able to response fast can be an option to PID controller.

In order to test governor's effect in utilization of DG spinning reserve during DG tripping and overloading cases, this paper proposes fuzzy logic control technique for governor and compares its response with PID based governor. For this purpose, a fuzzy based under frequency load shedding scheme is developed.When the DG is subjected to tripping or over loading cases, load shedding strategy operates to shed some load in order to stabilize the frequency. During this time, the response of DG with fuzzy based governor and PID based governor are compared to test which governor utilizes DG spinning reserve more quickly.

## Description of Fuzzy Based Load Shedding Scheme

The proposed UFLS scheme is based on two modules:
(1) Fuzzy logic load shedding controller (FLLSC)
(2) Load Shed Controller Module (LSCM)
The proposedUFLS scheme is illustrated in Fig.1.

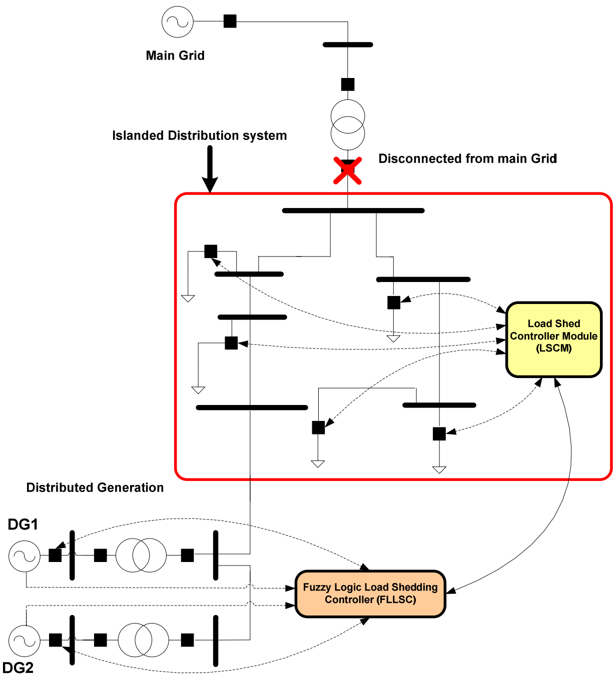


Fig.1. Layout of fuzzy based load shedding scheme

FLLSC uses frequency and *df/dt* information values as input, and determines type of load disturbance (DG tripping or load increment) and estimates the power imbalance during these disturbances. FLLSC sends this value to LSCM for shedding loads according to load priority. The loads are prioritized into three categories; vital, semi-vital and non-vital. The non-vital loads have the lowest priority and will be shed first followed by semi-vital and vital loads.

The islanded distribution network consists of two DG units with frequency *f1* and *f2* respectively. FLLSC checks whether any of DG unit is disconnected from network. If this happen, network frequency will follow to the frequency of DG unit that is still in operation. If both DG units are in operation, average frequency *(f)* of both DG units is taken.

Standard frequency pick value to begin load shedding scheme is set to 49.5Hz as practised in TNB, Malaysia [8]. FLLSC sends estimated value to LSCM via communication link. The delay time which includes calculation time, communication time and circuit breaker operation time is assumed as 100 ms, which is according to practical considerations [9,10].The co-ordination of under-frequency protection of generator with UFLS scheme is very important. If system frequency goes below certain threshold value, generator under frequency protection relay will operate and system will collapse unnecessarily. Hence, UFLS scheme should be applied in such a way that frequency recovers without going below prohibited value, which usually specified by turbine manufacturers is 47.5Hz [11].

## Proposed Methodology

### Fuzzy Based Governor modelling in PSCAD

Fuzzy based governor is modelled in PSCAD software, as it is a powerful tool for studying the transient phenomenon in electrical power system networks [12]. Fuzzy based governor for mini hydro power plants type DG consists of two inputs (frequency error and load)and one output (turbine gate). Fuzzy based governor receives frequency error and load (p.u) as input signal and sends controlling signals to servomotor for opening or closing the turbine gate. Modelling of fuzzy based governor is based on the modelling of fuzzification, rule base, inference mechanism and defuzzification steps as shown in Fig.2.

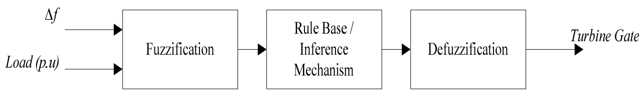


Fig.2. Block diagram of fuzzy based governor

Linguistic variables of frequency error membership functions are Vlow(Very Low), Low, Zero, High, Vhigh (Very High) and load membership functions are VSload (Very Small Load), Sload (Small Load), Nload (Normal Load), Hload (High Load), VHload (Very High Load). Linguistic variables of output turbine gate are Fclose (Full Close), Hclose (Half Close), Qclose (Quarter Close), Nopen (Normal Open), Qopen (Quarter Open), Hopen (Half Open), Fopen (Full Open).Input and output membership functions of fuzzy based governor are shown in Fig.3-5.

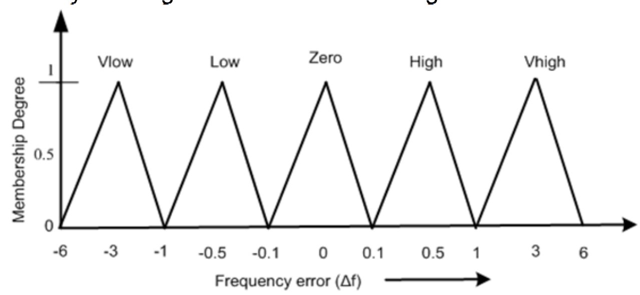


Fig.3. Frequency error membership functions

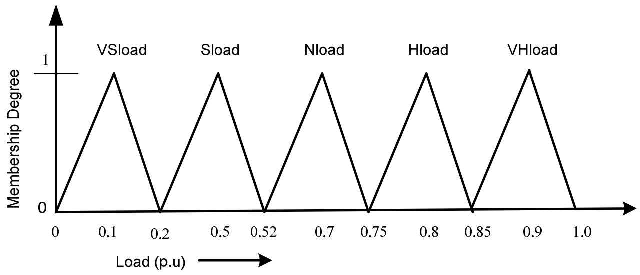


Fig.4. Load (p.u) membershipfunctions

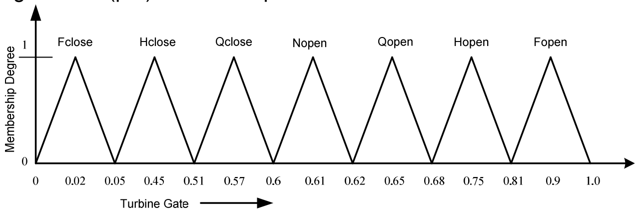


Fig.5. Turbine gate membership functions

Fuzzification step consists of converting the real input values into fuzzy set values.The fuzzy rule base is used in IF-THEN rule form to assign input and output control such as:

*IF frequency error is Vlow and load is VSload THEN turbine gate is Fclose.*

*IF frequency error is Vhigh and load is VHload THEN turbine gate is Fopen.*

The fuzzy based governor rule table is illustrated in Table 1.

Table 1.Fuzzy based governor rule table

| | | Frequency | | | | |
|---|---|---|---|---|---|---|
| | | Vlow | Low | Zero | High | Vhigh |
| Load(p.u) | VSload | Fclose | Hclose | Nopen | Nopen | Nopen |
| | Sload | Hclose | Qclose | Nopen | Nopen | Nopen |
| | Nload | Qclose | Qclose | Nopen | Qopen | Qopen |
| | Hload | Nopen | Nopen | Nopen | Qopen | Hopen |
| | VHload | Nopen | Nopen | Nopen | Hopen | Fopen |

The inference mechanism evaluates active signals for taking control actions from fuzzy rules. Finally, defuzzification is carried out through weighted average to convert the fuzzy linguistic variable into real crisp values.

### Fuzzy Logic Load Shedding Controller Modelling

Fuzzy logic load shedding controller plays an important role in the UFLS scheme. Since, major part of load shedding scheme depends upon it. FLLSC consists of two inputs and one output. The inputs are frequency *(f)* and rate of change of frequency *(df/dt)* and output is amount of load shed *(Lshed)*. Depending upon the input values, it estimates amount of load required to be shed which is sent to LSCM for shedding the required load. Block diagram of FLLSC is shown in Fig.6.

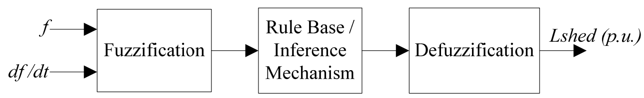


Fig.6. Fuzzy logic load shedding controller block diagram

Linguistic variables of frequency are Low (Low), Vlow (Very Low), EXtlow (Extremely Low), VEXtlow (Very Extremely Low) and rate of change of frequency *(df/dt)* membership functions are HN (High Negative), LN (Low Negative), LP (Low Positive), HP (High Positive). Linguistic variables of Lshed are Vsshed (Very Small Shed), Sshed (Small Shed), Bshed (Big Shed), Vbshed (Very Big Shed). The membership function of frequency, *(df/dt)* and Lshed are shown in Fig.7-9.

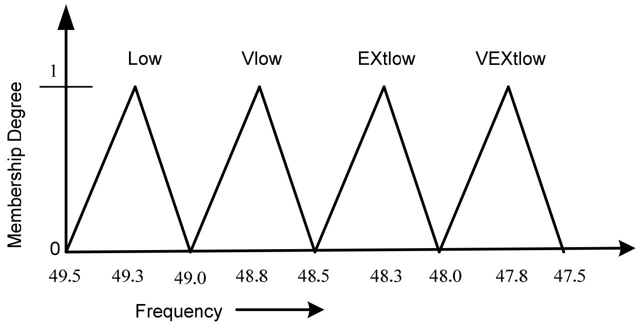

Fig.7. Frequency membership functions

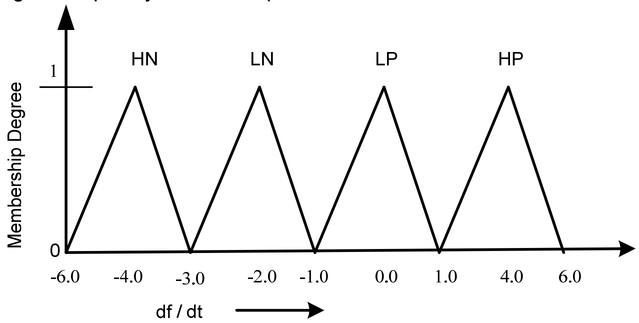

Fig.8. Rate of change of frequency *(df/dt)* membership functions

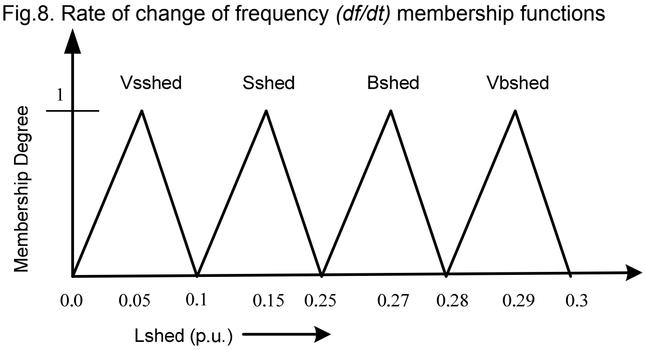

Fig.9. Lshed (p.u.) membership functions

The FLLSC rule table is shown in Table 2.

Table 2. Rule table for FLLSC

| | | Frequency | | | |
|---|---|---|---|---|---|
| | | Low | Vlow | Extlow | Vextlow |
| df/dt | HN | Sshed | Bshed | Bshed | Vbshed |
| | LN | Sshed | Sshed | Bshed | Vbshed |
| | LP | Vsshed | Vsshed | Ssshed | Sshed |
| | HP | Vsshed | Vsshed | Vsshed | Vsshed |

## Test System

Test system for this research consists of two DG units supplying power to islanded distribution network. The DG in this case is mini-hydro power plant. Mini hydro power plant mainly consists of small reservoir or irrigation canal, governor, turbine and generator. The water is passed from reservoir to turbine through penstock.When water strikes at the turbine blades, it converts hydraulic energy into mechanical energy. Water flow in the turbine is controlled through governor. Main function of governor is to control generator speed to keep its frequency constant.The turbine is coupled with generator which converts mechanical energy into electrical energy or power. The generated power is stepped-up through transformer and supplied to distribution network.DG units have total capacity of 4MVA. However, they are running at their base capacity (2.5MW). The distribution system consists of 27 buses and 20 lumped loads. In this study, distribution network is assumed to have reliable monitoring devices and fast communication system for transmitting data.The test system is shown in Fig.10.The load profile of distribution network is shown in Table 3.

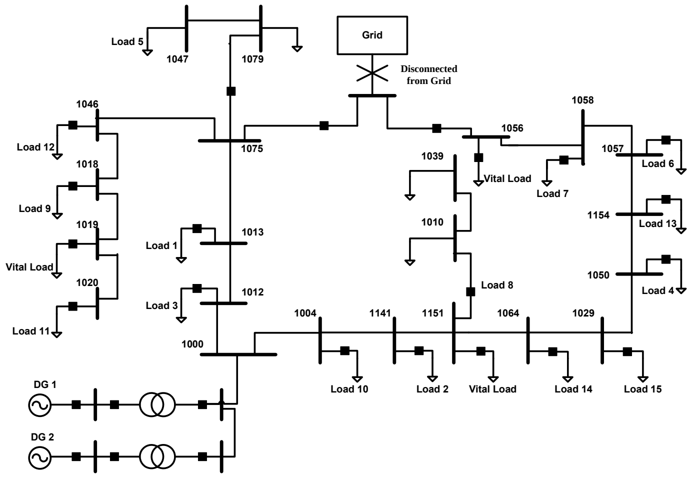

Fig.10. Test System

Table 3. Load Ranking Table

| S. No | Bus Number | P(MW) | Q(MVAR) | Load Category |
|---|---|---|---|---|
| 1 | 1013 | 0.0456 | 0.0282 | Non-vital |
| 2 | 1141 | 0.0531 | 0.033 | Non-vital |
| 3 | 1012 | 0.0531 | 0.033 | Non-vital |
| 4 | 1050 | 0.063 | 0.0384 | Non-vital |
| 5 | 1047-1079 | 0.11721 | 0.07281 | Non-vital |
| 6 | 1057 | 0.126 | 0.0768 | Non-vital |
| 7 | 1058 | 0.132 | 0.0819 | Non-vital |
| 8 | 1010-1039 | 0.15009 | 0.0933 | Non-vital |
| 9 | 1018 | 0.11619 | 0.072 | Semi-vital |
| 10 | 1004 | 0.14151 | 0.0876 | Semi-vital |
| 11 | 1020 | 0.1845 | 0.11439 | Semi-vital |
| 12 | 1046 | 0.1701 | 0.1053 | Semi-vital |
| 13 | 1154 | 0.1401 | 0.0849 | Semi-vital |
| 14 | 1064 | 0.093201 | 0.057801 | Semi-vital |
| 15 | 1029 | 0.2313 | 0.1431 | Semi-vital |
| 16 | 1019 | 0.10671 | 0.06609 | Vital |
| 17 | 1151 | 0.107199 | 0.06639 | Vital |
| 18 | 1056 | 0.35259 | 0.2187 | Vital |

## Result and Discussions

### Case 1: Governor's Response when One DG Tripped

To simulate this case, one DG unit is trip-off at t=10 s. Since, loads in distribution system are supplied by two DG units; loss of one DG will give a great impact to distribution system. In this situation, FLLSC checks frequency limit of 49.5 Hz. FLLSC estimates the amount of load to be shed and sends signal to LSCM, which immediately trip significant number of load feeders to stabilize DG frequency. Frequency response of DG with PID and fuzzy based governor for this case is shown in Fig.11.

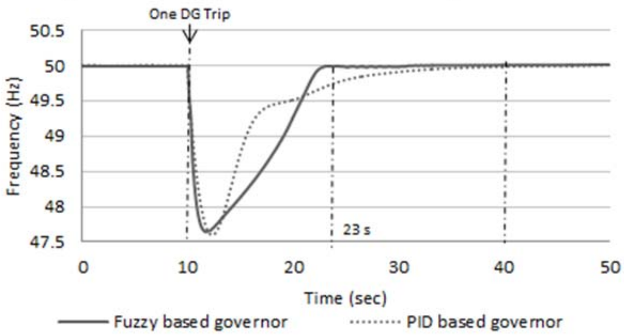

Fig.11. Frequency response when one DG tripped

Fig.11 shows that DG with fuzzy based governor has frequency undershoot of 47.65 Hz and frequency stables within 13s. However, DG with PID based governor has frequency undershoot of 47.62 Hz and frequency stables within 30s. Hence, DG with fuzzy based governor has smaller frequency undershoot and shorter settling time than a DG with PID based governor.The governor's response and amount of load shed for this case are shown in Table 4.

Table 4. Governor's response and load shed at DG tripping event

| Governor | Undershoot | Power Supplied | Load Shed | Power saving |
|---|---|---|---|---|
| PID Based governor | 47.62Hz | 1.47MW (73.5%) | 1.03MW | - |
| Fuzzy based governor | 47.65Hz | 1.6MW (80%) | 0.9MW | 6.5% |

It can be noticed from Table 4 that PID based governor enable DG to supply 73.5% (1.47 MW) load. Whereas, fuzzy based governor enable DG to supply 80% (1.6 MW) load. Thus, fuzzy based governor enables the DG unit to utilize 6.5% more spinning reserve of generating system than PID based governor. Thus, lesser load is shed in DG with fuzzy based governor case.

**Case2: Governor's Response with Load Increment Case**

To simulate this case a new load feeder rated 1 MW is suddenly connected to bus number 1047 in islanded distribution network at t=10s. FLLSC in this case checks for frequency limit of 49.5 Hz. FLLSC by measuring frequency and *df/dt*, estimates the amount of load to be shed and sends signal to LSCM, which immediately trip significant number of load feeders to stabilize the frequency. Frequency response of DG with PID and fuzzy based governor for this case are shown in Fig.12.

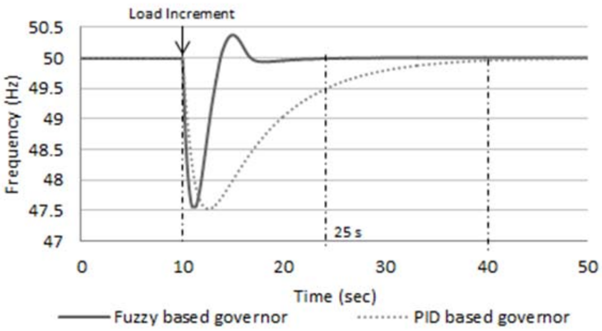


Fig.12. Frequency response during load increment case

Fig.12 shows that with PID based governor, DG frequency has undershoot of 47.52Hz and frequency stabilizes in 30s. However, with fuzzy based governor, DG frequency has undershoot of 47.56 Hz and frequency stabilizes in 15 s. Hence, DG with fuzzy based governor has smaller frequency undershoot and shorter settling time than a DG with PID based governor.Governor's response and amount of load shed for this case are shown in Table 5.

Table 5 Governor's response and load shed at load increment case

| Governor | Undershoot | Power Supplied | Load Shed | Power saving |
|---|---|---|---|---|
| PID based governor | 47.52Hz | 0.57MW (57%) | 0.43MW | - |
| Fuzzy based governor | 47.56Hz | 0.8MW (80%) | 0.2MW | 23% |

Table 5 shows that upon addition of new load feeder of 1 MW, DG with PID based governor supplied 0.57 MW load (2.5MW+0.57MW=3.07MW). However, DG with fuzzy based governor supplied 0.8MW load (2.5MW + 0.8MW = 3.3MW). Thus, fuzzy based governor enables the DG unit to utilize 23% more spinning reserve of generating system than PID based governor. Thus, lesser load is shed in DG with fuzzy based governor case.

**Conclusion**

When power system encountered DG tripping events or overloading cases, load shedding scheme is applied to shed some load to stabilize the frequency. However, this amount of load to be shed has close relationship with governor's response in utilization of DG spinning reserve. To verify this, thepaper has presented the comparison of fuzzy and PID based governor's response during these cases.From the simulation results, it can be concluded that DG with fuzzy based governor utilized more spinning reserve than DG with PID based governor and required lesser load to be shed. Furthermore, frequency response of DG with fuzzy based governor has smaller undershoot and shorter settling time than DG with PID based governor.

REFERENCES

[1] P.P.Barker,R.W. De Mello, Determining the impact of distributed generation on power systems. *I. Radial distribution systems, in: IEEE Power Engineering Society Summer Meeting,* , 2000, pp. 1645-1656 vol. 1643.
[2] H. Mohamad, H. Mokhlis, A.H.A. Bakar,H.W. Ping, A review on islanding operation and control for distribution network connected with small hydro power plant. *Renewable and Sustainable Energy Reviews*, 15 (2011) 3952-3962.
[3] M. Hanmandlu,H. Goyal, Proposing a new advanced control technique for micro hydro power plants. *International Journal of Electrical Power & Energy Systems*, 30 (2008) 272-282.
[4] Hydraulic turbine and turbine control models for system dynamic studies. *IEEE Transactions on Power Systems*, 7 (1992) 167-179.
[5] I.C. Report, Dynamic Models for Steam and Hydro Turbines in Power System Studies. *IEEE Transactions on Power Apparatus and Systems*, PAS-92 (1973) 1904-1915.
[6] D.P. Atherton,S. Majhi, Limitations of PID controllers, in: *Proceedings of the American Control Conference* 1999, pp. 3843-3847
[7] J.L. Culberg, M. Negnevitsky,K.M. Muttaqi, Hydro-turbine governor control: theory, techniques and limitations *in Proceedings of AUPEC* (2006) 1-5.
[8] A.A. Mohd Zin, H. Mohd Hafiz,M.S. Aziz, A review of under-frequency load shedding scheme on TNB system, in: *National Proceedings. Power and Energy Conference, PECon 2004*, pp. 170-174.
[9] IEEE Standard for Interconnecting Distributed Resources With Electric Power Systems. *IEEE Std* 1547-2003, (2003) 0_1-16.
[10] P.M. Anderson,M. Mirheydar, An adaptive method for setting underfrequency load shedding relays. *IEEE Transactions on Power Systems*, 7 (1992) 647-655.
[11] M. Lukic, I. Kuzle,S. Tesnjak, An adaptive approach to setting underfrequency load shedding relays for an isolated power system with private generation, *in: 9th Mediterranean Electrotechnical Conference, MELECON* 1998, pp. 1122-1125 vol.1122.
[12] K. Vinod, R.R. Joshi, R. Garg,R.C. Bansal, Intelligent Controller Based Improved Fault Ride-Through Capability of HVDC System Connected To Weak AC Grid. *Journal of Theoretical and Applied Information Technology*, 4 (2008).

***Authors**: Dr. Hazlie Mokhlis.Dr.A. H. A. Bakar, M.Karimi Department of Electrical Engineering, Faculty of Engineering, and UM Power Energy Dedicated Advanced Centre (UMPEDAC), Level 4, Wisma R&D UMUniversity of Malaya, 50603 Kuala Lumpur, Malaysia. E-mail: hazli@um.edu.my, a.halim@um.edu.my*
*H. Mohammad, Faculty of Electrical Engineering, University of Technology MARA, MalaysiaE-mail: hasmaini@hotmail.com*
*J.A. Laghari,Department of Electrical Engineering,QUEST University,Nawabshah, Sindh, Pakistan.Corresponding author: J.A.Laghari. E-mail: javedahmedleghari@gmail.com*