NEW APPROACHES TO LOAD SHEDDING PROBLEM IN ISLANDING SITUATION IN DISTRIBUTION NETWORKS WITH DISTRIBUTED GENERATION

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ABSTRACT

In electric power distribution systems with dispersed generation (DG), it is common to trip DG units in case of a sudden outage of a large generation unit. In new scenarios of operation of electric power systems keeping the DG units in an islanded distribution system is preferred. Load shedding is one of the most important measures in such distribution system that can be used to achieve this goal, but in fact it is the last chance for preventing a system blackout. In this paper, the frequency of the centre of inertia (COI) is proposed in an adaptive load shedding scheme. The proposed technique does not require communication between the components and real time system data; rather, it uses loads histories to shed the loads automatically with declining frequency.

INTRODUCTION

Reliable and secure operation of large power systems has always been a primary goal for system operators. There is global interest in distributed generation (DG) as an alternative to the centralized power plants. There are, however, various technical and economical challenges to bring this technology into the mainstream of a power market largely dominated by large centralized plants [1]. During emergency situation in the power system caused by generating power deficiency, frequency decline takes place. Dynamics of underfrequency during the deficiency of generation in the power system can have very different characteristics. It depends on the value of disturbance and response of emergency automation and governor system. For gradual increase in load, or for sudden but mild overloads, generating units' governors will sense speed change and increase power input to the generator. Here so called primary and secondary frequency control is activated. Sever system disturbances can cause fast frequency drop, which makes impossible fast governor and boiler response. If governor action cannot activate spinning reserve quickly, the system frequency is actuated. Automatic load shedding (UFLS) is a last resort tool to prevent the system from collapsing [2, 3]. UFLS schemes can be categorized into three groups: traditional UFLS schemes, semi adaptive UFLS schemes and finally the adaptive UFLS schemes [4]. The adaptive schemes are using the gradient of initial frequency to obtain the active power deficit in a system. In this way, it is possible to estimate a load which must be shed in order to balance the active power in the system. A traditional load shedding strategy has been presented in [5], which shed a fixed amount of load with decreasing frequency. Fast-acting load shedding was presented in [6]. Supervisory control and data acquisition (SCADA) based load shedding strategy has been proposed in [7]. Another load shedding algorithms which are related to the online measurement of the loads and load frequency characteristics is proposed in [8]. Load shedding methodology is related to loads frequency dependency. Loads with smaller dependency are shed first and those with larger dependency are shed later [9-12]. Even-though these methods are practical, real-time information on loads is not always available for small distribution systems and also using online load measurement is expensive. The load shedding strategy in islanded distribution systems should be treated differently from the large power systems because of the differences in characteristics. To calculate the amount of load to be shed, system inertia is needed. It is difficult to determine the amount of load to be shed when the system has significant penetration of generations that are stochastic in nature, such as wind turbines or photovoltaic powered generators. Islanded distribution systems often have small generators which have small inertia. So, the frequency tends to decay more rapidly. During such system disturbances, the generators are disturbed by inter-generator oscillations. Consequently, their frequency does not decelerate at the same rate. This is the reason why the frequency of the centre of inertia (COI) is needed to be calculated and the locally measured system frequency does not provide enough information. Consequently, the COI frequency is already widely used in various adaptive UFLS schemes. Using the COI frequency has been often used by a number of authors [9]–[17]. In a certain situations, not to be discussed here, the gradient can give misleading information about the active power deficit [13].

In this paper, an adaptive underfrequency load shedding in an islanded distribution system with DGs is presented. Here, we use COI frequency to estimate shedding loads and we don't use frequency gradient to regain the active power deficit so, we don't see lots of above problems. The proposed methodology is explained in detail and it is tested in a radial distribution system. The methodology is simulated in DigSILENT PowerFactory and the results are presented.

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GENERATOR OSCILATIONS

This section provides an overview of the theoretical background, which describes the generators' behaviour during a transient caused by a sudden change in the system's power balance.

Swing Equation of a Multimachine System

The swing equation for the ith generating unit can be presented as(1)

$$2H_i \times 2\pi \times \left(\frac{df_i}{dt}\right)(pu) = T_{a,i}(pu) \tag{1}$$

H_i is the inertia constant of the ith generator in seconds, df/dt is the first time derivative of the electrical frequency of the ith generator in p.u., T_{ai} is the ith generator accelerating torque in p.u.

To derive a swing equation for a multi machine system (with generating units), it is reasonable to imagine an equivalent generating unit that describes the average behaviour of all the generating units. This equivalent generating unit is called the COI.

Firstly, we use the common system base to obtain individual inertia constants as follows:

$$H_{i,sys} = H_i \times \left(\frac{S_{n,i}}{S_{base,sys}}\right) \tag{2}$$

Where $S_{base,sys}$ is the common power system base which is equals a pre-fault sum of all the island loads (P_{L0}). By applying the methodology that is given in [15], the COI electrical frequency $f_{COI,pu}$ and the inertia constant $H_{COI,pu}$ are given as follows:

$$f_{COI,pu} = \frac{\left(\sum_{i=1}^{n} f_{el,i,pu} \times H_{i,sys}\right)}{\left(\sum_{i=1}^{n} H_{i,sys}\right)} \tag{3}$$

$$H_{COI} = \sum_{i=1}^{n} H_{i,sys} \tag{4}$$

PROPOSED ALGHORITHIM

Loads are ranked based on their willingness to pay. A lookup table is created and loads are shed according to it. It is created by using the loads history and willingness to pay.

Frequency is measured every half cycle and df_{COI}/dt is calculated. If df_{COI}/dt is negative and lower than $df_{COI,L}/dt$ (corresponding to the lowest load) according to the Table 1 we find N and shed loads. After shedding we measure the frequency and obtain df_{COI}/dt. Methodology will wait for the frequency to go down below $f_{COI,L}$ and for df_{COI}/dt to be negative for T half cycles to shed another load which is located in the look up table.

To obtain a look up table we consider loads as fixed amounts and find df_{COI}/dt corresponding to a load by simulating an islanded condition in which a real power deficiency is equivalent to the load.

If the df_{COI}/dt calculated in power system is between the corresponding $\sum_{i=1}^{NO}(\frac{df_{COI}}{dt})_i$ of two loads, the N which shows the number of shedding loads is obtained by choosing the lowest $\sum_{i=1}^{NO}(\frac{df_{COI}}{dt})_i$ related to the load. For example, if the df_{COI}/dt calculated is -2.5 Hz/s and loads ranked 3 and 4 have $\sum_{i=1}^{NO}(\frac{df_{COI}}{dt})_i$ of -1.35 Hz/s and -3.05 Hz/s, respectively, then N is chosen as 4. The load shedding of N loads is initiated after the calculation of df_{COI}/dt and the determination of N from the look up table.

Table. 1. Look up table

NO	LOAD	$\frac{df_{COI}}{dt}$	$\sum_{i=1}^{NO}(\frac{df_{COI}}{dt})_i$
1	Load 09	-0.45	-0.45
2	Load 10	-0.45	-0.9
3	Load 11	-0.45	-1.35
4	Load 07	-1.7	-3.05
5	Load 08	-2.7	-5.75
6	Load JUEL	-3.4	-9.15
7	Load STCE	-3.56	-12.71
8	Load FLQE	-7.95	-20.66
9	Load STSY	-6.25	-26.91
10	Load STNO	-7.55	-34.46
11	Load MAST	-10.3	-44.76

After the first step of load shedding is initiated, the loads will wait for some time before they will measure the frequency again. Because of the calculations and circuit-breaker operation time, we face with the delay. Choosing T is related to a system specific and depends on the preference between optimal load shedding and a better frequency profile. In this paper, we choose T around 10 in which procedure can shed an optimal number of loads without letting the frequency to decrease to a very low value even in worst case scenarios.

MODELLING A REAL POWER SYSTEM

Analysing the performance of this is modelled in a real power system which is presented in Fiq. 1

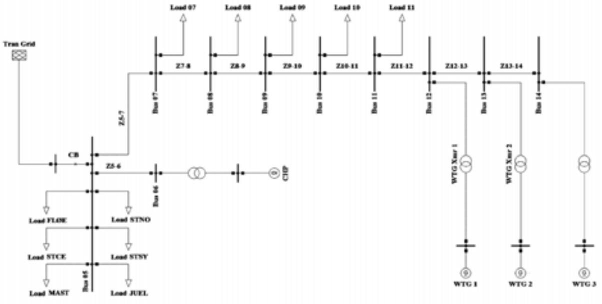

Fig. 1. Single line diagram of test system.

For the ease of comparison of the simulation results the case study is adopted from [18]. The test system consists of 3 fixed speed stall regulated wind turbine generators (WTGs) of 630 kW and a combined heat and power (CHP) plant with 3 gas turbine generators of 3 MW and 11 loads. Line data and generator data are given in [18]. An IEEE-type ST1 and GAST model, which are available in DIGSILENT, are used to model the exciter and governor system in the CHP plant, respectively. The data for exciter and governor systems and wind turbine system is given in Table 2, Table 3. The distribution system is connected to the transmission network at Bus 05. Islanding is simulated by opening the circuit breaker (CB). In our test system, $f_{COI,L}$ and T are set as 0.99 p.u. and 10 respectively. In our practical system, loads are voltage and frequency dependent. The data for loads are given in [18]. The CHP produced 9 MW and WTGs produced 84 kW each when the system was islanded. The delay time is chosen as 80 ms. For real assumption, we supposed that loads are voltage and frequency dependant. The loads are modeled as:

$$P = P_0\left(1 + K_{pf}\Delta f + K_{pv}\Delta V\right) \tag{5}$$

$$Q = Q_0\left(1 + K_{qf}\Delta f + K_{qv}\Delta V\right) \tag{6}$$

In which, k_{pf} , k_{pv} , k_{qf} , k_{qv} are all chosen as 0.5.

Table. 2. Excitation System Data

Parameters	Value
Measurement Delay (s)	0.
Filter Delay Time (s)	0.01
Filter Derivative Time Constant (s)	0.
Controller Gain (pu)	250.
Controller Time Constant (s)	0.01
Exciter Current Compensation Factor (pu)	0.
Stabilization Path Gain (pu)	0.01
Stabilization Path Delay Time (s)	1.
Controller Minimum Input	-7.5
Controller Minimum Output	-7.5
Controller Maximum Input	9.35
Controller Maximum Output	9.35

Table. 3. Governor System Data

Parameters	Value
Speed Droop (pu)	0.04
Controller Time Constant (s)	0.4
Actuator Time Constant (s)	0.04
Compressor Time Constant (s)	3
Ambient Temperature Load Limit (pu)	0.9
Turbine Factor (pu)	1
Frictional Losses Factor (pu)	0
Turbine Rated Power (MW)	0
Controller Minimum Output (pu)	0
Controller Minimum Output (pu)	1

RESULTS OF SIMULATION STUDIES

Circuit breaker is opened at t=0 s and the frequency drops and df_{COI}/dt decreases to -2.95 Hz/s at 0.01 s. It can be obtained from the look up table that N is 4. So the load shedding is started at t=0.01 s and after 0.08 s (delay time) loads ranked 1-4 are shed. At t=0.19 s, df_{COI}/dt is negative for 5 cycles and the frequency is below $f_{COI,L}$. So, N is become 5 and load ranked 5 is shed at t=0.27 s. No more loads are needed to be shed and the frequency is restored to its normal value. Fig. 2 shows system frequency without load shedding and Fig. 3 shows load shedding operation to restore frequency. Frequency rises to 49.7 Hz and steady state frequency is presented in Fig. 4.

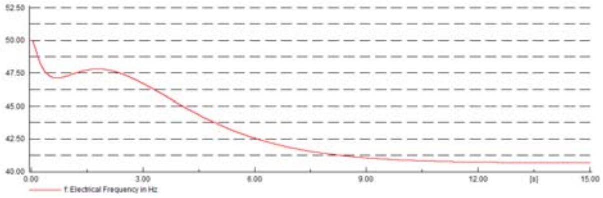

Fig. 2. system frequency without load shedding.

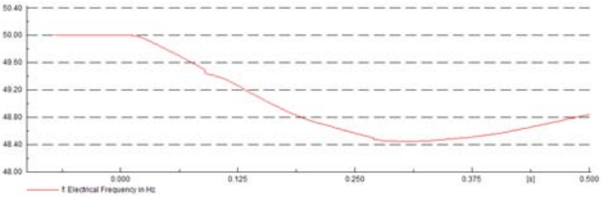

Fig. 3. system frequency during load shedding process.

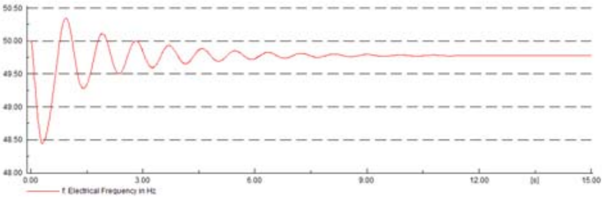

Fig. 4. steady state frequency after load shedding process.

CONCLUSION

The adaptive UFLS schemes are based on measuring the initial system frequency derivative. This measurement is used to calculate the active power deficit in an island. It is difficult to determine the amount of load to be shed when the system has significant penetration of generations that are stochastic in nature, the rated power of the connected generators and the current MW deficit that influence the load shedding amount is not fixed. Additional factors that must be overlooked are as follows: the initial system loading, the voltage profile of the system and consequently the load voltage characteristics. Without the information just mentioned the gradient could provide misleading information about the island's active power deficit value. However, during the transition to island operation the inter-generator oscillations appear in the islanded power system. The power imbalance is distributed among generators in two different manners. At the moment of islanding, it is distributed according to their synchronizing power coefficient and later on according to their inertia constants. The frequency of the COI is used in this method. The proposed technique does not require communication between the components and real time system data; rather, it uses loads histories to shed the loads automatically with declining frequency. This method provides accurate information about the system's total deficit value and requires fewer load elimination mentioned in [1]. The proposed underfrequency load shedding can stabilize the frequency of the distribution system with DGs when it is islanded by shedding an optimal number of loads. In this situation with a minimum control requirement, this distribution system can be considered as a micro grid.

REFERENCES

[1] P. Mahat, Z. Chen, and B. Bak-Jensen,2010, "Underfrequency Load Shedding for an Islanded Distributed System With Distributed Generation", *IEEE Trans. Power Del.* vol. 25, 911-918.

[2] R.S. Rabinovich, 2003, "Automatic frequency actuated load shedding system", *Energija*, 344.

[3] "IEEE Status Report on Methods Used for System Preservation During Underfrequency Conditions", *IEEE Transactions on Power Apparatus and System.* vol. PAS-94.

[4] B. Delfino, S. Massucco, A. Morini, P. Scalera, and F. Silvestro, 2001, "Implementation and comparison of different under frequency load sheding schemes", *Proc. Power Engineering Society Summer Meeting*, vol.1, 307-312.

[5] P.G. Harrison, 1988, "Considerations when planning a load shedding programme", *Brown Bovcri Rev*, no.10, 593-598.

[6] S.A. Nirenberg and D.A. McInnis, 1992, "Fast acting load shedding", *IEEE Trans Power Syst.* vol. 7, 873-877.

[7] M. Parniani and A. Nasri, 2006, "SCADA based under frequency load shedding integrated with rate of frequency decline", *IEEE Power Eng. Soc. General Meeting*, 1-6.

[8] X. Xiong and W. Li, 2006, "A new under frequency load shedding scheme considering load frequency characteristics", *Proc. Int. Conf. Power System Technology*, 1-4.

[9] P.M. Anderson and M. Mirheydar, 1992, "An adaptive method for setting underfrequency load shedding relays", *IEEE Trans. Power Syst.* vol. 7, 647-655.

[10] S.J. Huang and C.C. Huang, 2000, "An adaptive load shedding method with time based design for isolated power systems", Int. J. Elect. Power Energy Syst, vol.22, 51-58.

[11] D. Prasetijo, W.R. Lachs, and D. Sutanto, 1994, "A new load shedding scheme for limiting underfrequency", *IEEE Trans. Power Syst.* vol. 9, 1371-1378.

[12] V.V. Terzija, 2006, "Adaptive under-frequency load shedding based on the magnitude of the disturbance estimation", *IEEE Trans. Power Syst.* vol. 21, 1260-1266.

[13] U. Rudez and R. Mihalic, 2011, "Analysis of underfrequency load shedding using a frequency gradient", *IEEE, Trans. Power Del.* vol. 26, 265-275.

[14] P.M. Anderson and M. Mirheydar, 1990, "A low order system frequency response model", *IEEE Trans. Power Syst.* vol. 5, 720-729.

[15] P.M. Anderson and A.A. Fouad, 1977, *Power System Control and Stability*, The Iowa State Univ, Ames.

[16] H.You, V. Vittal, and Z.Yang, 2003, "Self-healing in power systems: An approach using islanding and rate of frequency decline based load shedding", IEEE Trans. Power Syst. vol. 18, 174-181.

[17] M.S. Pasand and H. Seyedi, 2007, "New centralized adaptive under frequency load shedding algorithms", *Proc. Conf. Power Engineering*, 44-48.

[18] P. Mahat, Z. Chen, and B. Bak-Jensen, 2009, "A hybrid islanding detection technique using average rate of voltage change and real power shift", *IEEE Trans. Power Del.* vol. 24, 764-771.