Adaptive df/dt Relay-A case study with reference to the Indian Power System

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Abstracts: df/dt relays are used in the power industry to rescue systems facing extreme disturbances to avoid system collapse. Traditionally, many computations are repeated to seek the proper power system settings such that the df/dt relay provides the desired good performance for selected scenarios. In this paper a case study of tripping of Farakka Super Thermal Power Station and proposed adaptive df/dt method for correct operation.

I. INTRODUCTION

THE maintenance of maximum service reliability has always been the primary concern of the electric utility industry. To attain this end, power systems are designed and operated so that for any predicted system condition, there will always be adequate generating and transmission capacities to meet load requirements in any system area.

For the most part, this design and operating procedure has been successful in producing a high degree of service continuity, even under emergency conditions. However, regardless of how great the planned margins are in system design and operation, there have been, and probably always will be, some unpredictable combination of operating conditions, faults, forced outages, or other disturbances which cause system split-ups and/or a deficiency in generating capacity for existing area loading. Sudden loss of generating capacity on a system will be accompanied by a decrease in system frequency. The frequency will not suddenly deviate a fixed amount from normal but rather will decay at some rate. The initial rate of frequency decay will depend solely on the amount of mismatch of load and generation and on the inertia of the system.

The Indian power grid comprising of NEW grid of installed capacity 1,48,818 MW and Southern grid (SR) of capacity 52,739 MW interconnected asynchronously, is considered to be one of the Very Large Power Grids in the world. By virtue of their capacity, such large power grids are characterized by a very high stiffness constant implying that a large perturbation (load-generation mismatch) is required to cause the grid frequency to change by 1 Hz. In case of NEW grid, the stiffness constant is of the order of 2000 MW / Hz. Further, for the same magnitude of perturbation, the rate of change of frequency (df/dt) will be much smaller for a very large power grid as compared to a medium sized grid. Thus, large sized grids are inherently resilient to rapid frequency fluctuations, unless triggered by complete loss of generation from a large generation complex or occurrence of a grid separation, and hence unlikely to experience a complete blackout due to rapid decline of frequency. This is corroborated by the fact that since its inception in 2006, the synchronous interconnection within the NEW grid has never been lost so far.

In Indian grid western region has a scheme of automatic shedding 6472MW load using df/dt relay and in Northern Region the quantum is 6020MW. In this paper different schemes of df/dt relay settings and proposed method for calculating frequency dip due to generation loss are discussed. In NEW/SR grid primary response is not available from most of the generating stations. As a result frequency change following a sudden load-generation imbalance is more than usual. The proposed scheme explores how under correction and over correction in df/dt activated shedding can be avoided.

II. WHAT IS df/dt RELAY

As a defense mechanism, df/dt relays are particularly effective in arresting the frequency collapse of a grid in the event of sudden loss of major generation. This is because by measuring the frequency decay rate, the corrective action can be initiated much ahead of the time when frequency of the synchronous interconnection would have actually dipped to a point at which generator under-frequency relays or unit auxiliaries would trip / operate leading to a complete system shutdown. The df/dt is used for load shedding in situations where sudden loss of generating capacity on a system will be accompanied by a decrease in system frequency. In such a situation of load Generation mismatch, the system frequency tends to fall. The df/dt relay can control the circuit breakers and allow feeders to be disconnected from the network, one by one.

A. df/dt Measurement principle by relays

Going through the technical information provided by various relay manufacturers, it is inferred that the relay adopts following measurement principles. The rate of change of frequency measurement is based on two successive frequency measurements and the time difference between the frequency measurements. The measured frequency value for df/dt calculation is averaged over three cycles. The accuracy of df/dt measurement depends on the accuracy of frequency measurements. This frequency measurement is carried out through time measurement of a cycle (time between two

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zero crossing). The measurements static error depends on the quartz crystal's absolute accuracy. The biggest error in frequency measurement is in the range of +/- 5% considering the time resolution of 1 micro second.[7] Some relays measure the change in frequency (Δ f) over a time interval (Δt=100ms), and calculate the df/dt every 5ms. They operate when the frequency change exceeds the setting value 50 consecutive times.[8] Technical data sheet of AREVA manufactured MICOM relays indicates that for frequency supervised rate of change of frequency 'f + df/dt' protection accuracy is +/- 5 % or +/- 5m Hz/s, whichever is greater.

B. Available df/dt relay settings

The minimum df/dt relay setting available is 0.1 Hz/sec However, other df/dt relays have a minimum setting of 0.2 Hz/sec only. Further as mentioned previously, error of +/- 5 % or +/- 6mHz (whichever is greater) is expected. The operation of the relay may be based either only on the rate of fall of frequency (negative df/dt) or both on a set frequency value and the rate of frequency decline (f< and df/dt). In addition, after the threshold condition is satisfied, the relay can be set to operate either instantly or with some time delay. However, it is to be appreciated that df/dt relays are intended to measure only the initial rate of fall of frequency experienced during the first few seconds following a load-generation imbalance, before primary response of online generators become effective. As such, the settings (f<, df/dt, delay etc.) of the relay may be decided by extensive dynamic simulation studies , based on historical data pertaining to past events of occurrence of significant load-generation mismatch

III. CHALLENGES OF IMPLEMENTING df/dt RELAY SETTING

The decay of system frequency following tripping of a large generator is not uniform at all nodes of the inter connection. Overloading of the neighboring generators causes their rotor speeds to slow down. However, the change in machine speeds is oscillatory in nature. These oscillations depend on the response of the generators and are seen differently at different locations. Consequently, df/dt is not identical if measured at different locations in the network, using PMUs. Moreover, the noise associated with the measured power frequency signal, may lead to erroneous measurement of df/dt and cause the relay to maloperate.

In NEW Grid most of the generation is located in eastern part while the major load centers and consequently df/dt relays are connected at Northern and Western part of the grid. In case of tripping of major generation in the eastern part, the decay in frequency will require a finite though very small time delay to be propagated across the rest of the synchronous interconnection. This is because the deficit created immediately after the tripping will initially be compensated by the kinetic energy stored in the rotating mass of the neighboring machines, rather than from those electrically distant from the location of the disturbance. Consequently df/dt relays at distant places will sense less value of rate of fall of frequency than at the location of disturbance. Correct operation of df/dt relay is therefore dependent upon the location of the relay from the disturbance. As per IEGC 2010, the permissible frequency band is 49.5- 50.2 Hz. If the grid is operating at the lower limit of this band, loss of even smaller generator, should cause df/dt relay to operate at other end whereas if the initial operating frequency be at the upper limit of the band, loss of even larger generation should not cause df/dt relay to operate.

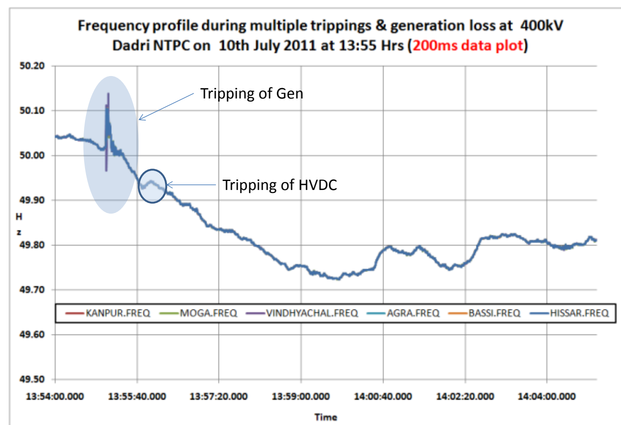
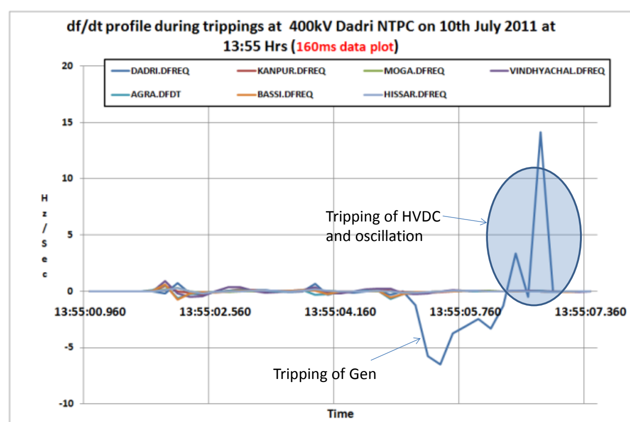


Fig. 1

Fig. 2



A. Case study

Multiple tripping of lines and generators took place at 13:55hrs on 10th July 2011 around Dadri (Stg-1, Stg-2 & G.P.S) complex. All running units of Dadri tripped, leading to loss of generation 1340MW. All 400kv and 220Kv lines emanating from Dadri also got tripped along with HVDC Rihand to Dadri. Fault was triggered from failure of Y ph CT of 400kV Dadri-Mandola-1 at Dadri. After loss of 1340MW Generation, system frequency decreased from 50.01Hz to 49.75Hz as shown in Fig. 1. Frequency change was well within the IEGC operating range of 49.5-50.2 Hz. In Fig. 2, df/dt recorded at some of the 400KV substation in Northern Region is plotted. It may be observed that the highest df/dt was recorded at Dadri, which was also continuously fluctuating during the first 2 second of the occurrence of the event. For correct measurement of df/dt and take necessary corrective action, it is therefore required to wait for some time to sense the appropriate operating condition.

IV. PROPOSED ADAPTIVE df/dt RELAY

From the above section major challenges and their solutions are as follows:-

(i) Operation of df/dt relay only when the frequency is below a certain value can be ensured by using <f+df/dt logic.

(ii) Time delay for correct measurement of df/dt can be solved by using T_{delay}+df/dt logic.

(iii) Actuation of df/dt relay only when the loss of generation is above a certain value can be guaranteed by using P_{loss}+df/dt logic.

It is possible to achieve all the above objectives by making df/dt relay adaptive. In the proposed adaptive df/dt relay, falling frequency is estimated which provides sufficient information regarding the disturbance in the system.

(i) If the estimated frequency is lower than the lower band of frequency of IEGC then relay may have to operate otherwise may not required to operate.

(ii) Intentional time delay is introduced to correctly estimate the time at which df/dt should be measured.

(iii) Complete loss of Power Plant will cause more |df/dt| as compared to loss of one unit of Power Plant.

Estimation of falling frequency

A typical variation of frequency and df/dt w.r.t time resulting from any disturbance shown in Fig.3 and the piece-wise linear estimation of df/dt in Fig.4. The df/dt at any point of time can be calculated once we know the equation of line ab, bc , etc.

The equation of line ab can be written as

$df_1/dt = m_1t + q$ ………………………………. (5)

Where "m_1" is the slope of the line ab and "q_1" is a constant, by putting t = 0 we can obtain value of q_1.

Now to obtain change in frequency w.r.t. time we need to integrate equation (5), hence integrating equation 5 we obtain

$$\Delta f_1 = m_1t^2/2 + q_1t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

now the above equation represents a parabola whose general equation is

$Y = aX^2 + bX + c$

For df/dt to again reach zero the condition should be

$$m_1t_1 = m_2t_2 \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where m_1 is slope of df/dt when it is decreasing and m_2 is slope of df/dt when it is increasing

As m_1, m_2 and t_1 are known so t_2 can be calculated from equation 7.

Now equation of bc line

$df_2/dt = m_2t + q_2$……………………………………(8)

at $t = t_1$, $df_2/dt= 0$

so q_2 can be calculate as m_2 is already known

again using $df_2/dt = m_2t + q_2$

Integrating this equation 8 w.r.t time

$$\Delta f_2 = m_2t_2^2/2 + q_2t_2$$

With the help of above equation Δf_2 can be estimated at the time of t_2. Total frequency fall after the disturbance will be f (initial frequency)-($\Delta f_1+\Delta f_2$)

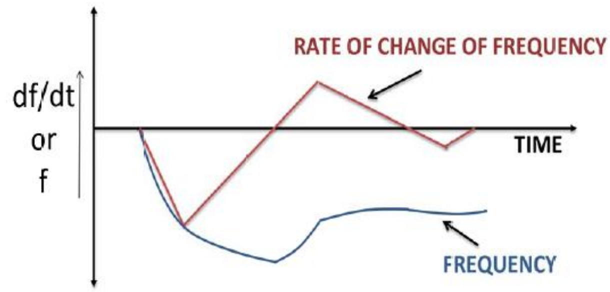


Fig.3

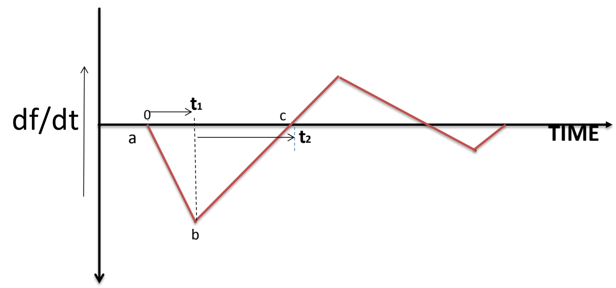


Fig.4

V. df/dt RELAY IN INDIAN POWER SYSTEM AND THEIR OPERATION

In order to restrict the low frequency due to sudden loss of generation in the grid, Automatic Under Frequency Load Shedding Schemes have been implemented in the constituent systems of WR (Table 1) and NR (Table 2) The schemes provide for automatic load shedding by Frequency Trend Relays (df/dt Relay).

TABLE 1

Settings	Recommended Load Relief (MW)	Implemented Load Relief (MW)					
Hz/(Hz./Sec)	Region	Region	GETCO	MPPTCL	MSETCL	CSPTCL	TPC
49.9/0.1(St-I)	2000	2000	1006	361	546	27	60
49.9/0.2(St-II)	2000	2000	905	355	621	37	82
49.9/0.4(St-III)	2472	2472	1001	392	686	120	273
Total	6472	6472	2912	1108	1853	184	415

TABLE 2

STATES	Load relief in MW			
	Stage-I 49.9Hz& 0.1Hz/sec	Stage-II 49.9Hz& 0.2Hz/sec	Stage-III 49.9Hz& 0.3Hz/sec	Total
Punjab	430	490	490	1410
Haryana	280	310	310	900
Rajasthan	330	370	370	1070
Delhi	250	280	280	810
UP	500	280	280	1060
Uttarakhand	70	70	70	210

VI CASE STUDY OF TRIPPING OF FARAKKA UNITS

At 19:58:38 Hrs of 16-03-12, loss of 1300MW generation occurred at Farakka Super Thermal Power Station of Eastern Region when multiple units of the station tripped due to delayed clearance of a line fault. Frequency and df/dt recorded by PMUs installed in Northern Region are shown in Fig 5 and Fig 6.

After the loss of generation, system frequency dipped from 49.95 Hz to 49.55Hz. i.e. 0.4 Hz in about 25 sec as shown in Fig. 6. In Fig. 5 df/dt recorded by PMUs at respective 400KV substations (in Northern Region) is shown. It may be observed that maximum df/dt was recorded at Vindhyachal and magnitude |df/dt| was continuously fluctuating with time. It is therefore required to wait for some time to sense the appropriate load-generation mismatch, before actuating the load-shedding relay for corrective action. Immediately after the loss of generation at Farakka, positive df/dt was recorded at Vindhyachal. Correct estimation of frequency fall therefore requires the information of total generation connected in the system prior to the disturbance and the magnitude of generation loss that is available centrally at the SCADA of National Load Despatch Centre (NLDC) for the entire country.

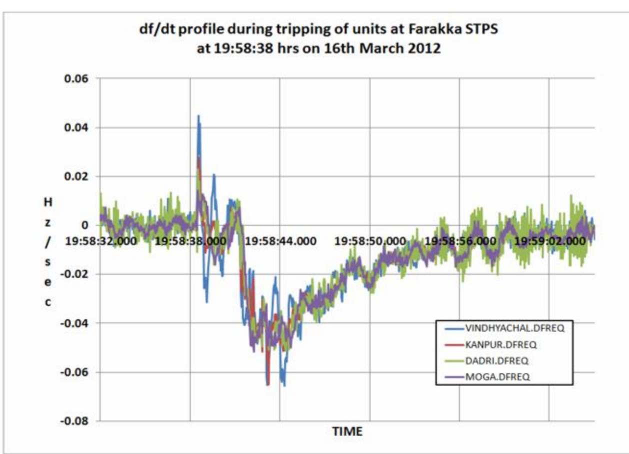


Fig.5

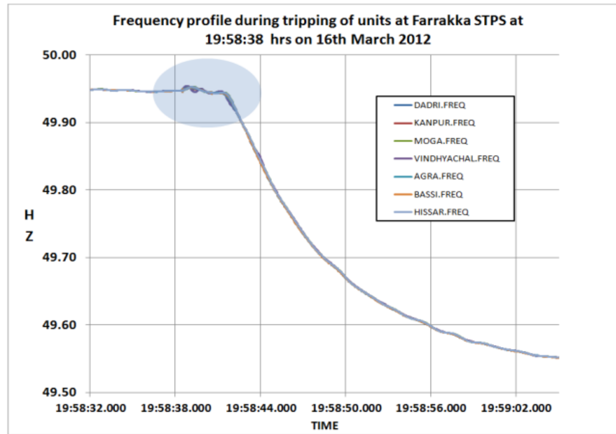


Fig.6

VII. SIMULATION WITH PSSE

ERLDC has a reliability group which carries out detailed off-line studies, for operational planning, contingency analysis and computation of ATC, TTC etc. The various flow gates of the region are monitored and their limits are duly considered while computing the TTC. For the purpose of Power System studies the Power System Simulator Engine (PSS/E) developed by M/S PTI is used.

In PSS/E package NEW grid has been modeled with load flow and dynamics data. Total generation in NEW grid was 75352MW and load was 72869MW. Initially the simulation was run for 5.0 sec without any perturbation Farakka four units (1300MW) were then tripped and the simulation run again for about 30 sec. Frequency dipped by 0.431Hz and df/dt was -0.065Hz/sec at Vindhayachal. it is shown in Fig.7 & 8. whereas df/dt at the other three locations was less. The highest sensitivity of Vindhyachal is obviously due to its minimum electrical distance from the source of disturbance as compared to Kanpur, Bassi and Moga. Further, the step increase of df/dt on the negative side in the simulated case is logically expected as there was loss of generation. However in the actual case the loss of generation was preceded by inception and persistence of an unbalanced fault around 53 km away from Farakka STPS. The initial positive jump of df/dt and its fluctuation on both positive and negative sides over the first 2-3 seconds may be attributed to such fault.

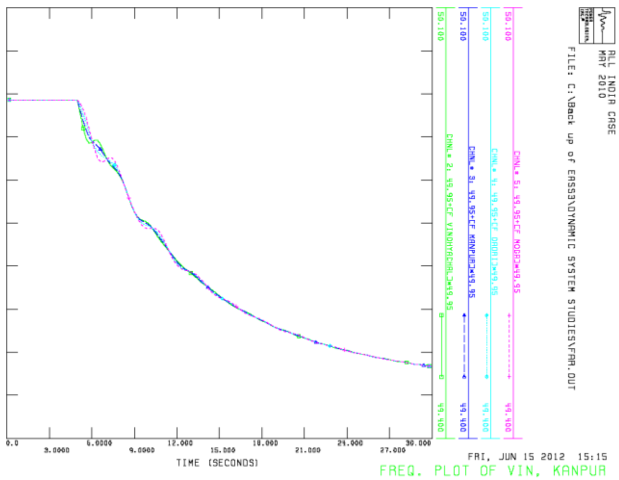


Fig.7

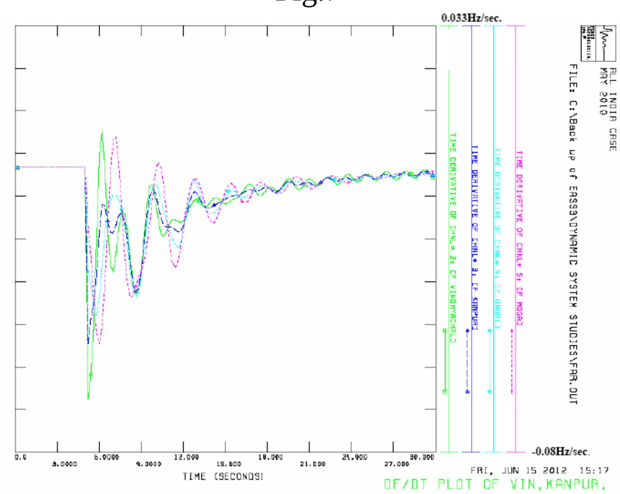


Fig.8

VIII. CONCLUSION

In India load and generation resources are not evenly distributed, with most of the generators concentrated at some pockets. As the major load centers are in NR and WR so df/dt relays are mostly connected there. In a large synchronized system, df/dt being sensitive to the location of the disturbance, tripping load just by measuring the local value of df/dt at a particular instant may lead to over correction or under correction. Thus an adaptive df/dt relay is proposed where load shedding will be done taking in account present generation, frequency of operation and magnitude of generation loss. With an adaptive df/dt relay the over correction or under correction can be avoided which will ensure security of the grid as well as minimize customer interruption.

ACKNOWLEDGMENT

The authors acknowledge with thanks the guidance and support given by management of POSOCO and for permitting the publication of this paper. The views expressed in this paper are of the authors in their individual capacity and not necessarily that of Power System Operation Corporation Ltd.

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