Live Line Selective Load Shedding

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Abstract— A power system has inbuilt capability to shed load automatically by voltage and frequency decline during the fault on transmission lines causing loss of generation. After the inception of heavy fault, the relays divide power system into multiple islands having varying frequencies and voltages. Natural 2% load reduction due to 1% frequency decline may be enhanced by rejecting loads using under voltage and under frequency relaying schemes to selectively disconnect auxiliary and noncritical loads as a demand side management strategy to overcome demand and supply deficits. This technique is good for live line load control instead of blanket load shedding equally affecting low and high demand consumers.

Keywords— UFLS, UVLS, UF Relay, UV Relay, Selective Load Shedding, Auxiliary Loads, Moderate Loads, Critical Loads.

1 Introduction

In power systems, most of the blackout take place because of frequency decline and voltage fluctuation as an aftereffect of generation-load imbalance. Modern Power systems are pushed to their stability limits because of heavily loaded conditions. Therefore, stability and reliability is the focal and basic issue of concern in network design and operation.

Frequency is a standout amongst the most reliable indicators of power system instability in events of overloading or faults. [1]. In a power system whenever the amount of power demand and supply equals the power system frequency remain constant. Be that as it may, a sudden reduction in generation capacity or escalation in demand cause rapid frequency decline. On the off chance that the frequency decline is not cancel out properly can bring about system instability and in a compelling circumstance it may lead for disastrous failures. In this way power system frequency and frequency control can be reflected as a measure of user satisfaction and system stability [2].

In vertically coordinated utilities, frequency response services were delivered through spinning reserve i.e. generators synchronized with system and available for load following in events of generation-load imbalance.

In reorganized power systems, these services are provided on the market basis [3]. It is fairly apparent that load can play a part fundamentally the same to generators for real power control in upholding balance between demand and supply. The most proficient methodology in an emergency is load shedding. In a broader perspective, when the potential outcomes that influence the system does not require exceptionally medicinal activities, then the load can be controlled [4].

But the existing rolling or blanket load shedding schemes affect all small and big consumers irrespectively of their loads categories. In these centralized load shedding schemes with Under Frequency (UF) and Under Voltage (UV) relays at Extra High Voltage (EHV) Grid Stations a predetermined amount of load is shed in events of frequency decline or overloading. Due to growing pressure for enhancing power system stability and reliability, utility companies are encouraged to local frequency sensing and load shedding schemes in the distribution system.

To mitigate the problems associated with currently implemented blanket load shedding schemes. In this research work, a concept of selective load shedding is being introduced to enhance the flexibility of power system and to involve residential and commercial users in the power system emergency restoration activities. The number of affected consumers having critical loads will be minimized by shedding auxiliary and noncritical loads in the event of fault or overloading. Furthermore the proposed load shedding scheme has the combine features of both under frequency and voltage load shedding schemes with distributed load control to achieve a good system performance and flexibility.

2 Under Frequency Load Shedding

Stable frequency is an essential requirement of a power system for safe mode operation. Stable and reliable services of both generators and loads are subject to stable frequency. In induction and synchronous generators, constant speed is obtained only with a constant frequency. Whenever the power demand and supply are equals frequency remain constant. But any sudden change in supply or demand cause frequency deviation. In the event that power system have no spinning reverse to overcome the supply deficiency than load shedding scheme is executed to maintain the balance between supply and demand.

Under Frequency Load Shedding (UFLS) is a standout amongst the most developed strategies in worldwide power systems to evade system collapse in events of faults or over-

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loading. In UFLS scheme, different frequency thresholds and the corresponding percentage of the load to be shed are pre-defined. Load shedding is executed when the point of coupling is reached and a number of frequency thresholds between 49.5 Hz and 48 Hz are used to execute load shedding. To inspect the impact of load shedding on the frequency, an appropriate delay is essential between the two consecutive load shedding steps [5-6].

The following steps are normally considered in UFLS scheme design [9].

A. Determining the anticipated overload

The amount of load to be shed is determined by using the value of estimated overload in the power system. The estimation of expected overload "L" is computed by

$$L = \frac{\text{Total Load} - \text{Total Generation}}{\text{Total Generation}} \qquad (1)$$

According to the equation "1", power system turns into 50 percent overload as a result of 33 percent generation loss. For estimating the generation load imbalance any value of "L" between 1-50 percent will be used. In any case, the estimation of "L" ought to be under 50 percent.

B. Selecting the Number of Load Shedding Steps

A concurrent detachment of calculated load in the event of frequency decline may bring about frequency over shooting. For that reason, load shedding is executed in several steps and a pre-define percent of calculated load is shed in each step. Usually 3 to 6 steps are recommended. A six-steps load shedding scheme with small percent of load to be shed in each step give better results for small disturbances, while three step load shedding scheme with a large percent of load to be shed in each step give better results for large disturbances [7-8].

C. Determining the Amount of Load to be shed at Each Step

The initial phase in load shedding scheme is the estimation of the total amount of load to be shed to retain the frequency within minimum acceptable boundaries. The total amount of load to be shed is calculated by

$$LD = \frac{\frac{L}{1+L} - d\left(1 - \frac{f}{f_n}\right)}{1 - d\left(1 - \frac{f}{f_n}\right)} \qquad (2)$$

Where,
LD = total load to be shed
L = expected overload
f= minimum permissible frequency
d=load reduction factor
f_n= nominal frequency.

Then the estimated amount of load to be shed is partitioned among several steps, according to implemented load shedding scheme.

D. Calculating Relay Settings

The last phase is to choose relay settings. After computing the amount of load to be shed in each step, the frequency at which load is shaded from step number one is estimated by using relay characteristic curves. Then, setting the next step determined using equation (3).

Setting = Prev. Clearing Freq. - Safety Margin (3).

3 Under Voltage Load Shedding

Voltage collapse is another most increasingly concern in power systems. There are numerous explanations behind the growing risk of voltage collapse i.e. constantly load growth, the varying nature of loads and distant locations of generating stations. Voltage instability generally happens because of fault followed by equipment failure, reactive power deficiency or tripping of generating unit.

Under Voltage Load Shedding (UVLS) is utilized as a last resort for power system protection whenever all other corrective measures exhausted. UVLS is used only in that scenario when voltage collapse (VC) is expected. The idea behind UVLS is that whenever a disturbance in power system drop voltage to a threshold for a pre-define time then some loads must be disengaged to keep up voltage within minimum permissible boundaries [9-10]. The purpose of UVLS scheme is that to uphold voltage stable, stay away power systems from voltage collapse and restrict voltage instability within the local area.

Following are some concerns to guarantee effective load shedding [11-12]:

A. The amount of load to be shed

Shedding an appropriate amount of load is a significant component for the viability of load shedding scheme. In order to guarantee accurate mitigation of the voltage decay an adequate amount of load must be shed in light of the fact that shedding of an inadequate amount of load may not capture voltage collapse accurately. While shedding of more load may prompt frequency overshooting.

B. Load shedding Location

Voltage is a local variable and relies on reactive power demand of a particular area. For that reason, UVLS must be carried out in that locations where voltage decay happens. Load shedding in another area may not be so effective to capture voltage collapse.

C. Timing and time steps of load shedding

To evade frequency overshooting load shedding is performed in several steps. An adequate time delay is vital before the execution of load shedding to evade needless tripping during transients.

D. Level of Voltage for Shedding

The voltage threshold for under voltage load shedding

must be just above the minimum acceptable boundaries of

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voltage. The voltage threshold at which load shedding is initiated is typically 8-10% below nominal voltage level.

4 Proposed Live Line Selective Load Shedding

In existing load shedding schemes which are known as rolling or blanket load shedding, normally load shedding is conducted by distribution companies on distribution level using time slabs and all consumers are affected equally, except certain priority consumers. But in the case of transmission lines overloading or the generation unit tripping transmission lines operators implement blanket load shedding using UF and UV relay to shed the supply of HV grid stations depending upon the difference between supply and demand.

To overcome the problems associated with existing blanket load shedding schemes. In this paper, we proposed a new combinational load shedding scheme of under frequency and voltage load shedding to selectively shed the consumer loads in the event of fault or overloading. Consumer loads are distributed among three categories i.e.

- Critical Loads
- Moderate Loads
- Axillary Loads

Their circuits will be controlled by one UV and three UF relays by setting suitable under frequency and voltage levels. Implementation of the scheme will shed consumer load after the point of coupling. The utility does not need to conduct load shedding at the distribution level. Different load categories and their corresponding frequency and voltage thresholds are shown in Table 1.

TABLE 1
Proposed Load Shedding Scheme Thresholds.

Sr. No.	Load Category	Frequency Threshold	Volatge Threshold
1	Auxiliary Load	49.8 Hz	215 V
2	Moderate Load	49.8 Hz	----
3	Critical Load	49.8 Hz	----

The block diagram of proposed live line selective load shedding scheme is shown in Figure 1.

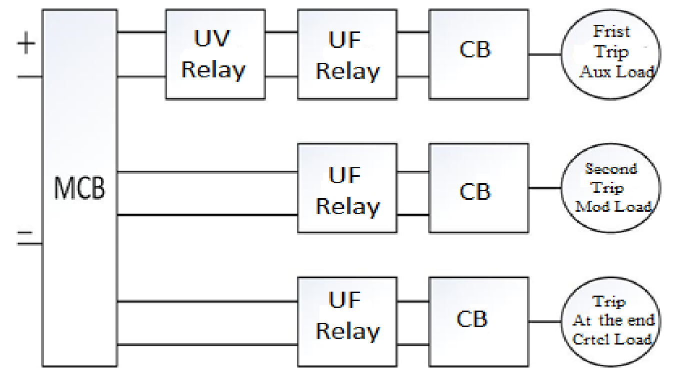

Fig. 1. Block diagram of proposed scheme.

5 Implementation Of Proposed Scheme In Matlab

To verify the correctness of proposed load shedding scheme. It is being implemented in MATLAB on 11kV distributed system with which a number of domestic consumers are attached through 11/0.4 kV transformer. The power supply to the consumers is provided by a synchronous generator of 2.5 MVA rating, with a 0.8 power factor its full load active power output is 2 MW. The 11kV generated voltage is then stepped down by distribution transformer to 0.4 kV line to line voltage or 230V line to neutral voltage. For the purpose of controlling the loads circuits, the under frequency and voltage relays are installed on 230 volts lines and their outputs are fed to the consumer loads. The MATLAB model of proposed scheme is shown in Figure 2.

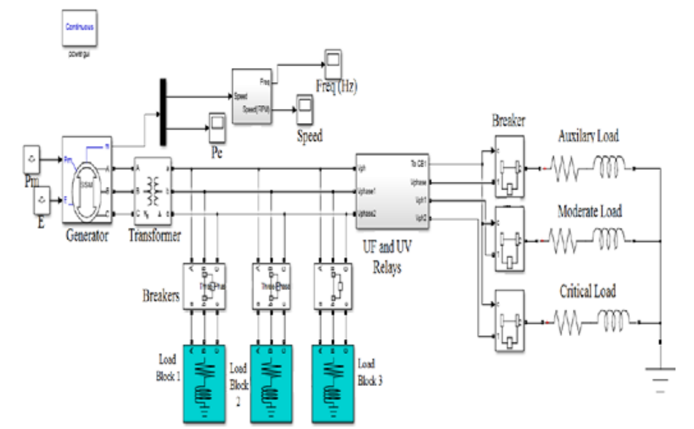

Figure 2: Simulink model of proposed load shedding scheme.

In this particular case, the total amount of domestic loads connected with the system is 1800 kW i.e. nearly equal to the full load capacity of generator. Domestic consumer connected loads according to their category are shown in Table 2.

TABLE 2

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Amount of Connected Loads with Generator.

Sr. No.	Load Category	Load Amount (kW)
1	Auxiliary Load	900 kW
2	Moderate Load	500kW
3	Critical Load	400kW

Whenever the amount of connected loads and supply are equal, all loads will be remain connected with the power system. On the other hand when any imbalance between demand and supply is observed, the auxiliary and moderate loads will be disengaged by under frequency and voltage relays connected in the consumer premise according to their thresholds setting. The variations in voltage due to load variations are shown in Figure 3.

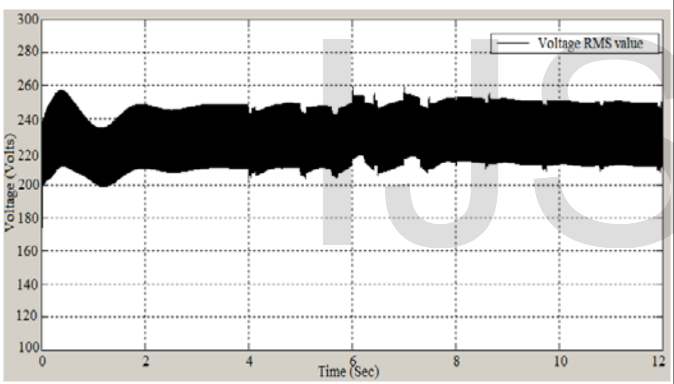

Figure 3: RMS value of voltage on consumer bus.

The variations in power system frequency with respect to load variations are shown in Figure 4.

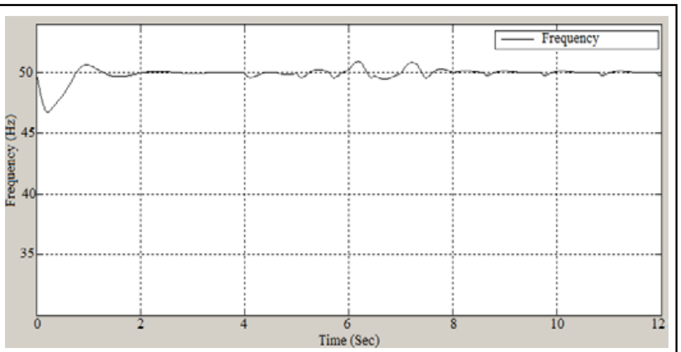

Figure 4: Frequency on consumer bus.

In events of faults or overloading the auxiliary and moderate loads are shed according to their frequency and voltage setting.

The RMS values of auxiliary, moderate and critical loads currents are shown in Figure 5.

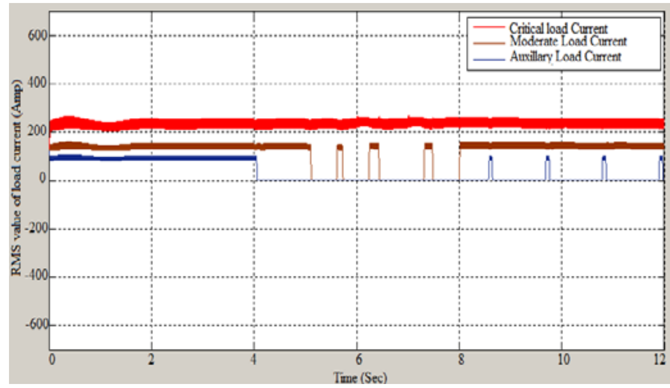

Figure 5: Consumer auxiliary, moderate and critical loads currents.

6 Haedware Implementation Of Proposed Scheme

A model of proposed load shedding scheme was developed in PROTEUS simulator and implemented in practical by using different electronic components that are easily available in local market. The design hardware consist of three main section i.e.

- Sensing unit
- Control unit
- Display

For steady and consistent operation of a power system, it is crucial that it's critical parameters i.e. voltage and frequency must stay inside of the minimum suitable limit. Contingencies may happen anytime in this manner it is important to consistently sense them and take corrective measures accordingly. The function of frequency and voltage sensing is performed by the sensing section of designed hardware.

Frequency sensing is carried out by using a potential transformer and a Schmitt trigger circuit, incoming 230V supply is stepped down to 5V by a potential transformer and Schmitt trigger circuit creates a square wave for incoming supply.

Voltage sensing is carried out by a potential divider circuit and a potential transformer which step down incoming 230V incoming to 5V. When the 2.5V DC voltage from potential divider circuit is added to potential transformer output a 0 to 5V DC offset voltage is generated for incoming voltage.

Load circuits as for their thresholds setting are controlled by a microcontroller. Frequency and voltage sensing circuit's outputs are fed to the controller which compare the incoming signals with their corresponding thresholds and after the point of coupling reached then it shed the corresponding load category.

An LCD display is used to show the status of each load category and actions performed by microcontroller. The schematic diagram of hardware is shown in figure 6.

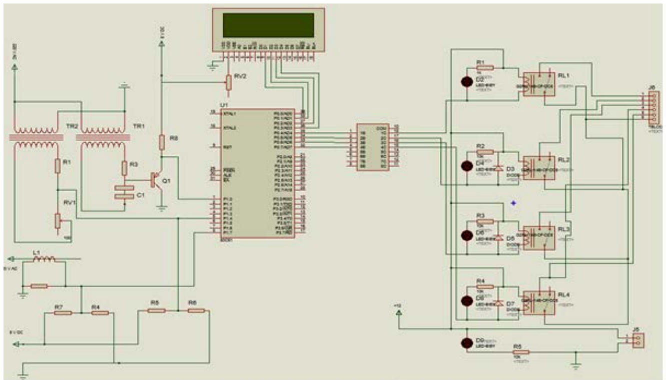

Figure 6: Schematic diagram of microcontroller based load shedding.

7 Conclusion

The natural 2% load reduction with 1% frequency decline is reinforced by rejecting loads in event of fault or overloading using under frequency and voltage relays. The selective shedding of auxiliary and non-critical loads in event of fault or overloading reinforce the power system stability and improve customer's satisfaction at the same time. After inception of fault or overloading the auxiliary and non-critical loads are shed to stabilize overloads generators and their connectivity are restored when fault is cleared and frequency become greater than threshold setting. The distribution of loads in critical and non-critical categories help us to tackle the problem of varying frequencies and voltages and improve customer satisfaction.

References

[1] R. Hassan, M. Abdullah, G. Radman, F. Marco, S. Hammer, J.Wigington, J. Givens, D. Hislop, J. Short, S. Carroll. "Under-Frequency Load Shedding: Towards a Smarter Smart House with a Consumer Level Controller" Proceedings of IEEE Southeast Conference, Vol., no., pp. 73-78, 2011.

[2] Y. R. Omar, I. Z. Abidin, S. Yusof, H. A. Hashim, H. A. Abdul Rashid. "Under Frequency Load Shedding (UFLS): Principles and Implementation" IEEE International Conference on Power and Energy (PEC), Vol., no., pp., 2010.

[3] K. Samarakoon, J. Ekanayake. "Demand Side Primary Frequency Response Support through Smart Meter Control" Proceedings of the 44th International Universities Power Engineering Conference (UPEC), Vol., no., pp. 1-5, 2009.

[4] K. Samarakoon, J. Ekanayake, N. Jenkins. "Investigation of Domestic Load Control to Provide Primary Frequency Response Using Smart Meters" IEEE Transactions on Smart Grids, Vol.3, no., pp.282-292, 2012.

[5] L. J. Thomas, J. Wu, J. B. Ekanayake, N. Jenkins. "Enabling Distributed Frequency Response Using Smart Meters" IEEE PES Innovative Smart Grid Technologies (ISGT Europe), Vol., no., pp.1-5, 2012.

[6] D. Jay, K. S. Swarup. "Frequency Restoration using Dynamic Demand Control under Smart Grid Environment" IEEE PES Innovative Smart Grid Technologies, IEEE PES Innovative Smart Grid Technologies (ISGT India) Vol., no., pp.311-315, 2011.

[7] I. A. Hiskens, "Load as a controllable resource for dynamic security enhancement," presented at the IEEE Power Engineering Society Annual Meeting, Montreal, QC, Canada. June, 2006.

[8] A. Molina-Garcia, F. Bouffard, and D. Kirschen, "Decentralized demand-side contribution to primary frequency control," IEEE Transactions on Power Systems, No. 99, 2011.

[9] S. Lu, N. Samaan, R. Diao, M. Elizondo, C. Jin, E. Mayhorn, Y. Zhang, and H. Kirkham, "Centralized and decentralized control for demand response," in Innovative Smart Grid Technologies (ISGT), IEEE PES, IEEE, pp. 1-8, 2011.

[10] D. Trudnowski, M. Donnelly, and E. Lightner, "Power-system frequency and stability control using decentralized intelligent loads," in Transmission and Distribution Conference and Exhibition, 2005/2006 IEEE PES. IEEE, pp. 1453-1459, 2006.

[11] M. Donnelly, D. Harvey, R. Munson, and D. Trudnowski, "Frequency and stability control using decentralized intelligent loads: Benefits and pitfalls," in Power and Energy Society General Meeting, IEEE, pp. 1-6, 2010.

[12] A. Molina-Garcia, F. Bouffard, and D. Kirschen, "Decentralized demand-side contribution to primary frequency control," IEEE Transactions on Power systems, No. 99. 2011.