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Smart Grid: Protecting The Power Grid From Collapsing, featuring Load Frequency Estimation and Control

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***Abstract*— System frequency is one of the most important parameters of a power system. Due to generation-load mismatches, the system frequency can vary over a small range. When the power consumed by loads and overall losses is greater than the generated power, the operating frequency of the system will decrease, resulting in a situation known as the underfrequency condition. In some other case, if some of the loads in a system are disconnected from the system suddenly, or lost, it leads to a condition called as the overfrequency condition. This condition is characterised by greater input power than the consumed power by the loads. The rest of the loads in the system will absorb the extra power and the generator inertia, leading to an increase in the system frequency. In both the cases, the system frequency fluctuates from the power system's limited frequency range, futher leading to tripping off of the substation and further collapsing of the entire system. The paper describes a new method employing a smart meter to monitor and control the power system frequency- which changes according to the loading conditions in the system, whether underload condition or overload condition. The estimated frequency is being compared with a reference frequ ency value set by the Load Despatching Authority and the line responsible for the frequency change is being isolated from rest of the power system or being given only the demanded power . The parameters of electric power-based on load forecasting is being analized for setting the reference frequency. The method is employed with an embedded system along with an algorithm and connected with the central monitoring server via cloud computing. The simulations were carried out using MATLAB/Simulink software and Proteus Professional Software.**

Index terms - Power system frequency; load frequency control; frequency estimation; Adaptive Notch Filter Algorithm; load forecasting; Cloud Computing.

I. INTRODUCTION

The promise and goal of a smart grid is to enable a more intelligent, efficient, and reliable power grid with increasing user visibility and participation [1]. Technology has progressed to that extent that, it is possible for anyone to monitor the grid efficiently and cheaply. Also with simple signal processing techniques and inexpensive equipments, could enable researchers from all over the world to observe local power grids in action from a large number of points. The additional visibility would promote new insights and improved understanding toward a more reliable efficient power grid.

The smart grid is the convergence of information technology, communications, and power system engineering to provide a more robust and efficient power system. Information and communications technology (ICT), and in particular, wireless communications will be integrated into the power grid for active operation, and efficient demand response in the smart grid. The smart grid supports bi-directional communication to facilitate real-time metering of customers. It also permits the utility to control consumer loads so as to maintain the system parameters in safer limits.

In this proposed paper, a method to prevent gird from collapsing is being proposed , which employs smart meters to control and monitor the power grid .the Load Frequency is being controlled and monitored for the prevention of grid collapse.

In this paper , the author estimates the frequency of the system using three methods viz, Least Mean Square Algorithm, Adaptive Notch Filter Algorithm and Discrete Fourier Transform Algorithm. The efficiencies of the three methods were compared on the basis of Peak Signal to Noise Ratio [PSNR] and the best algorithm is employed for the proposed approach for smart metering. The simulations were carried out using MATLAB Simulink Software for frequency estimation and Proteus Professional Software for the synchronisation and control of the smart metering module ,mainly for the microcontroller part employed in the smart meter.With the preset value supplied by the concerned power supplying authorities, the estimated frequency is being compared and so the load frequency control is being implemented for the entire system using a microcontroller and an algorithm for controlling the frequency. Indeed the consumer gets a better user visibility by this approach.

II. LOAD FREQUENCY ESTIMATION

The frequency of the system must be maintained between the safer limits , so that the system will be able to

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transmit power from the generator side to the utility load side in an effective way. This can be done by carefully monitoring the system frequency or by estimating the system frequency, known as frequency estimation. The author studied and analysed a few frequency estimation techniques viz, Least Mean Square algorithm [LMS], Adaptive Notch filter algorithm [ANF]and Discrete Fourier Transform algorithm [DFT].

A. Least Mean Square algorithm

Least Mean Square Approximation [6] technique involves the least mean square of errors approximation as its name shows. One may see intuitively that when more data is used in a least mean square approximation, the error of the estimation will be reduced. In other words the longer the data window used, the smaller the effect of noise on the output. However, this is only partially true, because the foundation of this algorithm is not the least mean square approximation, but the approximation of the input waveform with the Taylor series expansion.

The least error square approximation only builds upon the results of the Taylor Series Expansion. Hence, error is being introduced from the start. When a larger window is used, more expansion terms will be required to give an accurate approximation of the longer waveform.

B. Adaptive Notch Filter algorithm

The adaptive notch filter algorithm [3]estimates the frequency of the system irrespective of any time. There exist some practical applications in which signals are not pure sinusoidal and contain harmonics. That is, it estimates instantaneous frequency of the signal, whatever change occurs on the signal at any time instant.The filter employs a continuous-time frequency estimator, like Hsu structure[15]. The adaptive notch filter's [ANF] stability is been modified by Averaging theorem .

C. Discrete Fourier Transform algorithm

Frequency estimation algorithm employs the relationship between phasor (usual DFT) angles and deviated frequency. The algorithm adjusts the sampling frequency (i.e. sampling interval ΔT) so that an integral number of samples per cycle are maintained. First, rough frequency estimation for a data window is computed using a second-order least error square approximation on the phasor angles of the input waveform. Next, a resampling based on the rough frequency estimation is carried out, and this is then followed by another second order least square error approximation to obtain the final results.

III. Load Frequency Control

Storage capacity in the power grid is very limited. So, the generation must track the demand soo closely. In other word, the generated power must be simultaneously utilised by the demanding consumer loads. If the generation P_G is not matched to the load P_L, the generators slow down, converting some of the kinetic energy from spinning motion into electric energy. The rate at which this occurs is dependent on the inertia of the system. This conversion is reflected in changes in the frequency at which the power grid operates. If enough energy is not produced by the generators corresponding to the demanded load, the system frequency decreases; if the demanded load is lower than the power generated, the frequency increases.

In equation form the energy balance is,

$$P_L = P_G + \frac{2H}{f0}\frac{d}{dt} f_D + \beta f_D$$

β is the frequency response of the system encompassing changes in generation with respect to frequency and changes in the load with respect to frequency. H is the per unit inertial constant of the system. The deviation of the frequency from the nominal value f_0 is given by f_D. If imbalances were allowed to continue unchecked the grid would quickly spin out of control, as the substation collapses due to drastic change in system frequency from the safer value.

Proposed Block Diagram

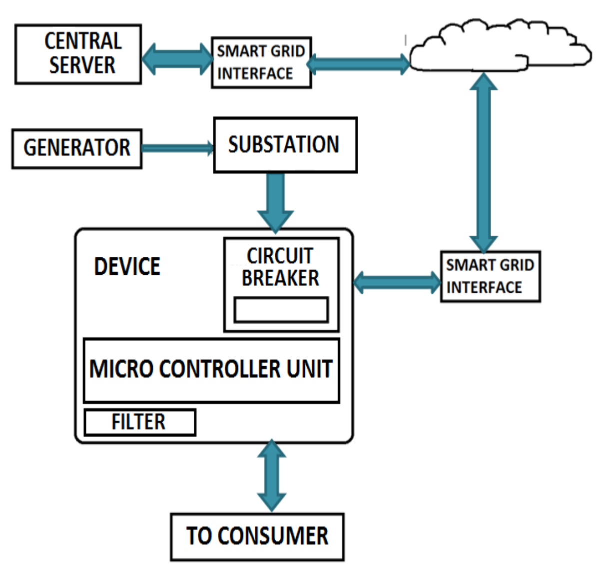

Fig.1 – Block diagram showing the load frequency control

IV. Proposed Approach

The system frequency is being sensed and the analog power signal from the transmission line is being converted into a digital signal using an Analog to Digital Converter[ADC]. The ADC is being embedded in a Microcontroller. Using a mechanism, voltage from wall outlet voltage levels ,which is analog is converted into digital signals. The microcontroller , which is also embedded with frequency estimation algorithm , estimates the instantaneous frequency of the system. This estimated value of frequency is being fed to the microcontroller programming part, where program is carried out to check whether the input value of estimated frequency ranges between the specified reference range.

The preset frequency range is being loaded into the microcontroller by the synchronisation methods like Global Positioning System [GPS] or Cloud Computing [CC]. The author is using CC as, it can use a large number of virtually created memory and can feed the information and the preset values of the frequencies and synchronise with the microcontroller. The microcontroller used for the simulation is PIC18F452 .If the estimated system frequency doesn't range in the safer value, the program feeds instruction to a programmable relay so that , the relay isolates the overloaded line [line causing the system frequency to go above or below safer limits]. Thus the load is kept away and the system frequency is maintained within safer value. The feeding and monitoring of the system frequency range is being carried out by the Load Despatching Authority.

All the above hardware module is being incorporated inside a smart meter, and is being connected between the substation and line feeding the load of utility side. A proper record of the process taking place are also being recorded and fed to the Load Despatching Authority and the concerned substation. User is also given the privilege of checking and monitoring the changes taking place.

V. Cloud Computing

Cloud computing is a time synchronisation technique, that involves a large number of computers connected through real-time communication network such as the internet. This system uses the memory of the connected computers so that , as a whole, the user utilising this synchronisation technique gets a large space to store the data. Moreover, it relies on maximizing the effectiveness of the shared resources, thereby enhancing faster response. By employing cloud computing , the user can transfer or access data with no time delays and better synchronisation of data is possible.

VI. Performance Study

The instantaneous voltage was sensed by the ADC and the filter , which is actually the proposed algorithm for frequency estimation. The researcher carried out simulations for each of the mentioned algorithms and compared the efficiencies of each technique on the basis of PSNR and the frequency estimation using MATLAB. The results are tabulated based on the number of samples , such that the author experienced visible difference in the performance and accuracy when the samples were increased. The simulations were also carried out for the microcontroller part.

A. Frequency Estimation Using MATLAB

As the approach is related to smart grid, incorporating real time monitoring of the power system , the evaluation of the parameters must be done with large number of samples , so that the efficiency of the approach is closely met. For the performance study , the number of samples chosen were 1000, as higher the number of samples , more the PSNR value and the efficiency of the algorithm.

The input signal[Fig.2], which is the sinusoidal system signal [power signal] with frequency as 50 hertz is given as input to the filter [ANF Algorithm].

As like in any system , here also the input signal contains noises. Here the noise is set with an experimental value - 0.7. Due to the presence of noise , the signal fed into the filter [power signal] as input will not be a pure sinusoidal signal , but a combination of the pure input sinusoidal signal and the noise fed[Fig.3]. Here the noise supplied is white guassian noise.

In the Adaptive Notch Filter Algorithm , the noise is being filtered for further frequency estimation [Fig.4]. The amplitude spectrum showing the estimated frequency is also shown[Fig.5]

For the simulation, the frequency was estimated as near to 50 Hz system frequency [f=49.804]. The PSNR was found out as 51.746, ie greater than the PSNRs got from both LMS algorithm and DFT algorithm. That is, it shows that the noises are being eliminated and the frequency is being estimated more or less closely accurate with the original system frequency as the power of the peak signal is greater than the noise signal.

TABLE.I shows the PSNR Ratios and the Estimated Frequencies for all the filtering algorithms.

TABLE I.

S.No	LMS	ANF	DFT
No. Of Samples	1000	1000	1000
PSNR	50.171	51.746	47.431
Estimated Frequency	49.80 Hz	49.80 Hz	49.80 Hz

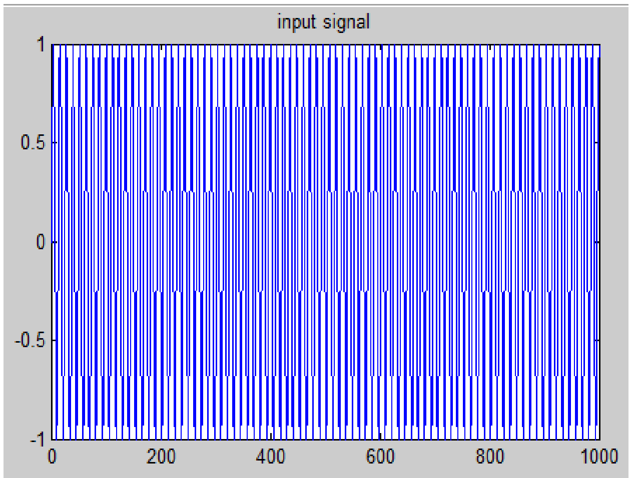

Fig. 2- Sinusoidal input signal

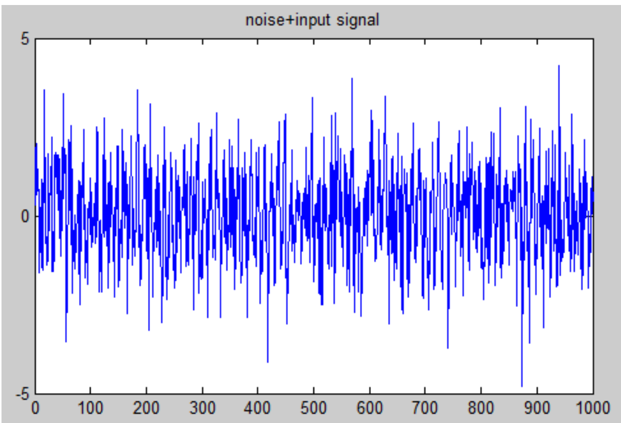

Fig. 3- Combination of input signal and noise signal

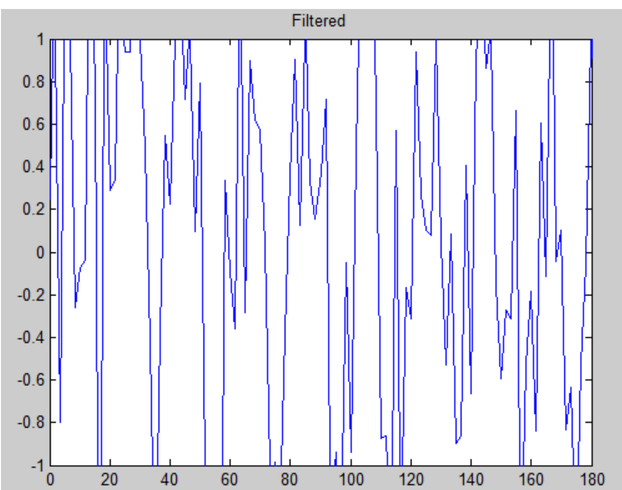

Fig. 4- Plot showing the filtered signal

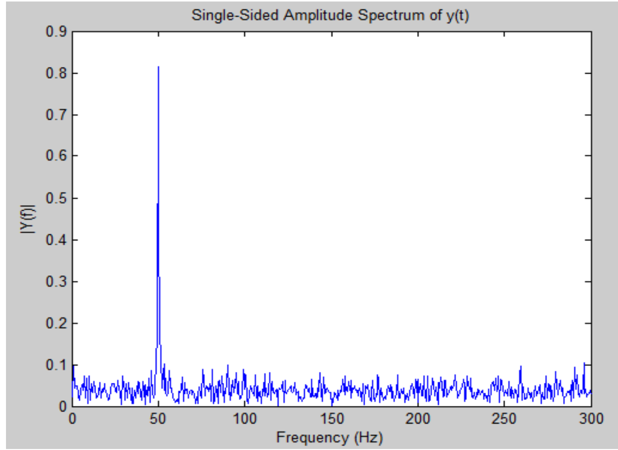

Fig. 5- Amplitude spectrum showing the estimated frequency

B.Simulation of Microcontroller

The system frequency, estimated as a numerical value is being fed into the microcontroller as the input. The microcontroller used is PIC18F452.The microcontroller is loaded with the control program to check whether the input frequency value lies within the given specified frequency range.If the frequency is within the specified range, the microcontroller sets a high bit to the control port of circuit breaker, so that the circuit breaker remains closed , thereby connecting the load with the supply. The analog value of frequency got by the ANF algorithm (49.80Hz) was fed as the input to the microcontroller, which is converted by ADC. The ADC conversion is shown in the simulations provided which is in binary digits [Fig.6]. The microcontroller converted this value into binary digits by the ADC converter and fed into the program for checking whether the value lies within safer limit. As the the input frequency (49.80Hz) was within the given range , the circuit breakers control port was triggered with a high bit set by the microcontroller [Fig.6]. The frequency was varied to see the under frequency and over frequency conditions too. Suppose the frequency is above or below the frequency range specified in the microcontroller, the microcontroller assigned a low bit to the control port of circuit breaker, there by opening the circuit breakers connecting the respective loads with the supply side [Fig.7] and [Fig.8] respectively .

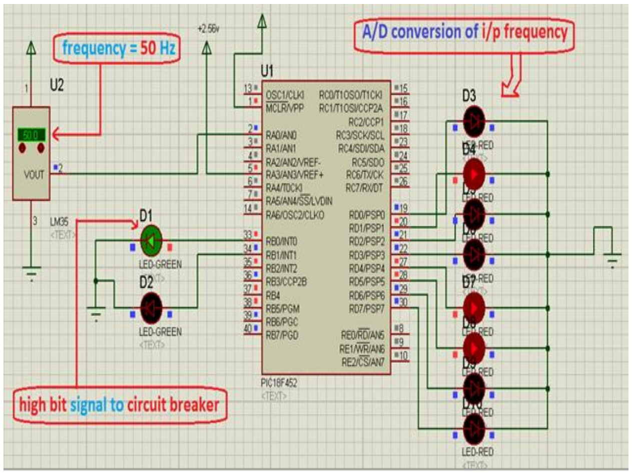

Fig 6- when the frequency lies within safer range (49.5 Hz to 50.5Hz)

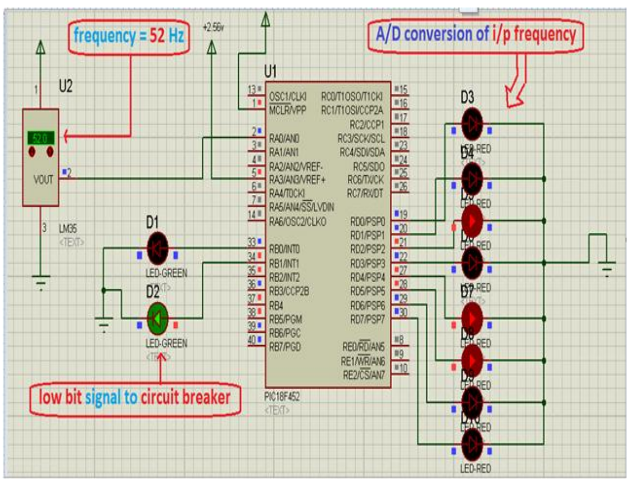

Fig 7- when the frequency goes above the safer range (above 50.5 Hz)

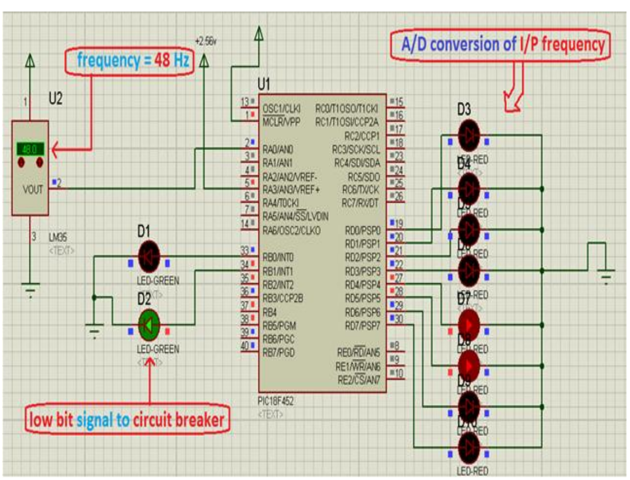

Fig 8- when the frequency goes below the safer range (below 49.5 Hz)

VII. Conclusion

In this paper, the protection of grid system from within the substation level is being discussed which may lead to an increase in efficiency of the entire power grid. Using different frequency estimation techniques, the system power frequency is being calculated or measured and with a respective program, the power system is being protected from collapsing or tripping off. The main advantage of the proposed approach is that, as it operates within the power system, mainly monitored and operated by the Load Despatching Authority, better control of the system is attained. The parameter chosen in this approach is system frequency which can be controlled even individually ,. Thus it provides the governing authorities an added advantage to attain a much more efficient system. The user can also get the privilege of knowing the changes occurring within his line.

VIII. Future Aspects

The approach explained in this paper can be developed more . The parametric criteria like current, power factor and voltage of the power system can be controlled even individually, by incorporating the respective values with the algorithm with a few changes. Also with the synchronization technique [Cloud Computing] used here provided instant real time operation. Message alerts , instant e-bills related to power consumed by the user, can be supplied to the user. If the system parameters like power factor and system frequency of any particular load side varies regularly, thereby causing changes in the system and affecting the stability and efficiency , the Authorities can penalize the corresponding users. The authorities can even terminate the connection of the users from the Load Despatching Centre itself by respective instruction feeder into the central server with a speedy notification. Thus the traditional system can be replaced with a smarter , efficient , intelligent system , thereby making the grid much more smarter.

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