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HARMONISED AUTOMATIC FREQUENCY LOAD SHEDDING (AFLS) SCHEME FOR THE COTE D'IVOIRE-GHANA-TOGO-BENIN POWER POOL

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ABSTRACT

La Cote d'Ivoire, Ghana and Togo-Benin have operated an interconnected power system for almost two decades. There exists an energy exchange between Ghana and La Cote d'Ivoire. Togo and Benin are supplied with energy directly from Ghana and/or indirectly by La Cote d'Ivoire by wheeling through Ghana. As the case in power pools, a disturbance in one power system affects all the utilities constituting the pool. This sometimes can result in widespread power interruptions and may even cause total system collapse. The stability of the power pool is very crucial to the reliability of supply in each of the utilities. System voltages and frequencies are also of major concern especially in the sub-region where power demand is fast outpacing power supply. To guarantee power system stability, acceptable voltage profiles and operating frequencies, the interconnected system has been developed to operate effectively to match generation with demand at all times. This paper seeks to describe the Harmonized Automated Frequency Load Shedding scheme that is operated by the interconnected utilities in the sub-region: the Volta River Authority (VRA) of Ghana, Compagnie Ivorienne d'Electricité (CIE) of la Cote d'Ivoire and Communaute d'Electrique du Benin (CEB) of Togo-Benin.

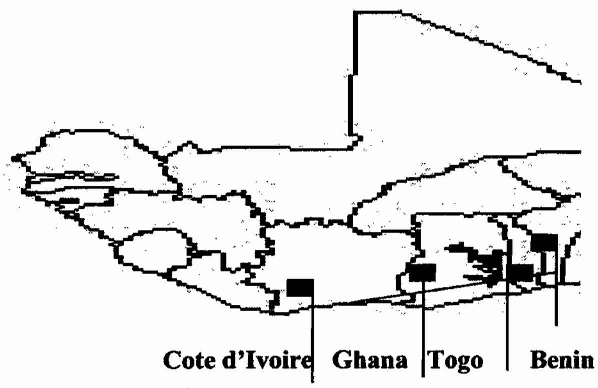
Key Words: Power system stability, Power pool, Operating frequency, Generation, Demand.

2. INTRODUCTION

La Cote d'Ivoire, Ghana, Togo and Benin, are geographically situated along the West African coast. They have historical and socio-economic links. La Cote d'Ivoire has a geographical area of about 322,000 km^2 and a population of about 15 million while Ghana has a geographical area of about 240, 000 km^2 and a population of about 18 million. The per capita income for La Cote d'Ivoire is about $450 while that of Ghana is about $400. Togo and Benin who operate a joint power utility (CEB) have a combined area of about 200,000 km^2. The population of Togo is about 4.5 million and that of Benin is about six (6) million. Their per capita income is about $300. The power systems of la Cote d'Ivoire, Ghana, Togo and Benin are presently synchronously interconnected. The VRA system has been connected to the CEB system at Lome, Togo from Akosombo by a 130km dedicated 161kV double circuit transmission network since 1972. From Lome the 161kV lines continue east through Cotonou in Benin, ending at Sakete near the Benin-Nigeria border (see Figure 1).

In 1984, CEB commissioned a 66MW hydroelectric plant – the Nangbeto Plant located in the centre of Togo and tied to the 161kV transmission network. Earlier, in 1983, a 220km, 225kV single circuit line was commissioned between the Prestea substation in Ghana and Abobo substation in la Cote d'Ivoire. The four countries have therefore operated an interconnected power system since 1983 through the utilities of CIE, VRA and CEB. The benefits of interconnecting the power systems of the various utilities, countries or regions include the financial gain in the optimum use of available generating capacity in the system, an increase in the overall technical performance of the utilities in the interconnected system and reduction in the total expansion costs. The CIE of la Cote d'Ivoire has an installed capacity of 1200MW half of which is hydro and the other half thermal. The national peak load is about 580MW. The VRA of Ghana operates a total installed electricity generation capacity of 1,652MW. This is made up of 1072MW of hydro and 580MW of thermal. The domestic peak load is about 1200MW. CEB of Togo/Benin, including other generators, has total installed generation capacity of 170 MW with 65MW hydro and 105 thermal. The combined peak load of Togo and Benin is about 135MW.

Figure 1. Countries with interconnected power systems



The interconnected system therefore has an installed capacity of about 2910MW and a peak load of about 1890MW. Even though the installed capacity far exceeds the peak demand of the interconnected system, the variable hydrology in the sub-region, the relatively higher production cost of thermal power and maintenance activities of the various components of the interconnected system limit the reserve margin. In effect, the actual reserve margin or spinning reserve is so limited that in event of a loss of a large generating unit, the only viable option is to shed load automatically to maintain system stability. Another crucial factor that makes the use of the spinning reserves less effective is that the loss of relatively large generating units, about 160MW, cannot be easily taken up by the available reserve margin on the other units.

Any unexpected decrease in the balance of power in the system therefore has the potential of causing interconnected network instability and insecurity. The imbalance of generation and load will lead to the decrease in network frequency, which if allowed to persist may lead to a total shut down or collapse of the power system. It is therefore crucial to re-establish the power balance between generation and demand in the shortest permissible time by load shedding. The load shedding should prevent at all cost the collapse of the power network and thereby ensure high degree of power supply quality. It is imperative to structure the load-shedding scheme in a coordinated manner to minimize the effect of system disturbances especially, the ones that are associated with the loss of generating units or the Ghana-Cote d'Ivoire tie line.

2. AFLS-CONCEPT

Under normal steady-state operating conditions in a power system, the total power generated is equivalent to the total consumption of customers and system losses:

$$P_t = P_c + P_l \quad (1)$$

Where, P_t is total power,

P_c is total consumption and,

P_l is the losses.

The total power in a grid is the sum of the power generated within the power system and that imported from external sources in an interconnected system. In the situation where the power is lost due to a loss of a generator unit or disconnection of the interconnected system through switching or relay operations from faults, there will be a deficit in real power. This will result in the slowing of turbo-generators and a consequent reduction in system frequency. The extent of reduction in frequency will depend on the following:

1. The proportion of the deficit DP to the total power of all generators still in operation.
2. The Moment of Inertia of all rotating machines in the power system, which is characterized by H, the constant of inertia, which is the ratio between the kinetic energy and apparent power of the rotating machines.
3. The load reduction factor Ko that defines the influence of frequency reduction on the real power requirements of the loads.
4. The type of turbine governor and the value of the spinning reserves.

The first two influencing factors determine the initial rate of the frequency reduction i.e. what is referred to as the frequency gradient at t=0 to which the following equation applies:

$$\frac{df(O)}{dt} = \frac{-DPf_N}{2H} \quad (2)$$

Where f_N is the rated frequency of the power system. Typical values of H in seconds are:

Diesel Engines	1 - 3
Combustion turbine, SC	2 - 5
Combustion turbine, CC	2 - 7
Steam turbine	3 - 10
Hydro generators	2 - 5
Turbo generators	2 -10

It should be noted that for a system with various types of machines, an averaging method is used to calculate the net H. For example;

$$H_{net} = \frac{H_1 \times MVA_1 + H_2 \times MVA_2 + ...}{MVA_1 + MVA_2 + ...} \quad (3)$$

Where MVA_1, MVA_2 etc are the various ratings of the generators with corresponding moments of inertia of H_1, H_1, etc

The load reduction factor, the type of governor and the spinning reserves determine the remainder of the frequency characteristic. If there are no spinning reserves and the turbo alternator sets in operation are fully loaded, the loss of the highest capacity generator in the system may lead to loss of synchronism and subsequent system collapse. This can only be avoided by shedding sufficient load to re-establish a balance between generation and load. An automatic under frequency load shedding scheme performs this function. In an interconnected system, same as the VRA-CIE-CEB network, it is essential that load-shedding scheme is harmonized in order to achieve a stable and reliable system. The benefits of the harmonized load-shedding scheme are:

- Improved system stability by each utility
- Guaranteed system stability during loss of generation
- Assured frequency stability
- Scheme suitable for the interconnected & separated system operation

- Avoid automatic disconnection of thermal generators
- Eliminate collapse of power system.

3. IMPLEMENTATION STRAFTEGY

Before the implementation of the harmonized load-shedding plan it was observed that VRA and CIE had their own independent load-shedding schemes. These schemes were based entirely on the circumstances of the individual utility. For instance in VRA the load-shedding plan was a combination of rate frequency decay and flat frequency. In the CIE system the plan used only flat frequency, with lower settings than that of VRA. CEB did not use load shedding at all.

Clearly the differences in the loading-shedding plan was a source of stability problem and that was exactly the situation with the participating utilities blaming each other for system instabilities. In the bid to coordinate all such schemes in the power pool, the sub-technical committee of the VRA and CIE instituted studies into the harmonization of the load-shedding schemes of the interconnected utilities.

The VRA on its part held series of meetings with its major consumers to discuss the modalities and implications of the harmonized load-shedding scheme. VRA held a similar meeting with CEB, which was expected to be a major player in the scheme. As was envisaged, consumers approached the meeting with apprehension and mixed feelings. After much deliberation an agreement was reached with the various utilities and the take-off date was fixed for January 28, 2001 throughout the interconnected system.

3.1 The Load Shedding Settings

The defense plan against the sudden large deficits is by a coordinated five-stage Automatic Frequency Load Shedding (AFLS) scheme for the participating countries. This plan, which was the outcome of the VRA/CIE Sub-Technical Committee studies, was considered relevant for reliable and stable operation of the CIE-VRA-CEB interconnected system (Table 1). About 40% to 50% of the total interconnected system peak load of VRA-CIE-CEB has been subjected to the control of the AFLS scheme for the five stages. This quantum of load is considered a sufficient guarantee for maximum network stability for the worst contingencies including the loss of the tie-line between VRA-and CIE. The plan also guarantees a reliable and stable network operation of each utility during stand-alone situations. Due to the fact that relative (%) generation deficit may be large and that power spinning reserve may be provided by hydro generating units, the use of relays sensitive only to frequency may be insufficient to prevent operation of thermal generating units whose under frequency setting is 47.5Hz. Therefore frequency relays with rate of decay function (df/dt) have been used for the scheme at predictable major load areas.

3.2 Implementation

The VRA already, since 1978, employed frequency relays with df/dt functions for load shedding at Volta Aluminum Company (Valco), an aluminum smelting company and a VRA major consumer. Additional relays with df/dt functions were therefore procured for the full implementation of the harmonized AFLS scheme.

The CEB also procured a number flat frequency relays for the scheme. CIE also already had a lot of flat frequency relays in their system employed for load shedding scheme. In order to implement the scheme at the stipulated date VRA loaned CIE two relays with df/dt function.

Table 1. Adopted Five-stage Automatic Frequency Load Shedding (AFLS)

Load Shedding (MW)							
Stage	Freq (Hz)	df/dt	Time (ms)	CIE	VRA	CEB	TOTAL
1	49.50	-0.30	150	20/30	70/80	10/15	100/125
2	49.50	-0.50	150	20/30	70/80	10/15	100/125
3	48.50	-	150	20/30	70/80	10/15	100/125
4	48.10	-	150	20/30	70/80	10/15	100/125
5	47.70	-	150	20/30	70/80		100/125
Total				100/150	350/400	50/70	500/625

The scheme was initially to be put into service by the three utilities on January 28, 2001. However, owing to a few logistical problems, it was put into service in April 2001. Installation work involved with the implementation of the plan was undertaken by the participating utilities in-house with their respective distribution companies. The df/dt relays were mostly installed at Bulk Supply Points where the predictability of loads is high. The flat frequency relays were installed at smaller substations within the distribution networks.

In the case of Ghana, the loads were selected on the basis of their criticality or consequential damages. For instance the Hospitals, the National Broadcasting Station, the Mines and other such loads were either not affected at all or placed at the last stage of the AFLS plan.

3.3 Observations

It was observed that since the implementation of the scheme, there has not been any system collapse of the VRA network. The other observation was that the

Maximum individual customer interruption duration (MICID) had reduced. Averagely we needed over 40 minutes to fully restore power supply under system collapse but any customer interruption due to AFLS would normally have the supply restored in 5-10 minutes. This may however depends on the gravity of the generation deficit.

3.4 Problems

The distribution company in Ghana, which is without a SCADA system, has to rely on customer complaints to detect outages thereby prolonging some customer outages. At some other locations the situation is improved by the use of handy-talkie transceivers. Various initial customers complaints about un-announced power supply disruption have to be tackled through customer education. The customers graciously understood the rationale behind the un-announced disruptions. Another problem encountered was the need to buy more relays in order to spread out coverage areas to avoid power interruptions to large sections of communities.

3.5 Cost Consideration

The cost of interruption of service is made up of a fixed cost because an interruption has occurred and a variable cost that increases the longer it takes. Below are various graphs that relate interruption time to its cost.

From these graphs, for high sensitivity loads, the cost of interruption can be represented by:

Industrial	$y = 1/5x + 55$
Commercial	$y = 2/3x + 100$
Residential	$y = x + 50$

For non sensitive loads

Industrial	$y = 2/3x + 20$
Commercial	$y = 2/3x + 20$

Where x is the duration of interruption in minutes and y is the cost-times normal KWhr rate.

4. FUTURE POSSIBILITIES

There is the consideration of employing the relays, which also have over frequency functions, to reclose customer loads after AFLS operations when the system frequency returns to normal. This however would require more studies and knowledge of experiences of other utilities if any. The VRA is currently retrofitting its generators at Akosombo with uprated capacity and faster electronic governors. This would have to be factored into future studies since the higher capacity rating and faster response time of the governors will have effect on frequency.

In the situation that the VRA-CIE-CEB power pool is synchronously linked to other utilities or pools like that envisaged with Nigeria Electric Power Authority (NEPA), the AFLS scheme would have to be reviewed to accommodate the expansion.

CIE currently supply SONABEL of Burkina Faso with a radial 225kV transmission line to Bobo Dioulasso, in the West of Burkina Faso. VRA and SONABEL have long been engaged in discussions for VRA to supply power to the capital of Burkina Faso, Ouagadougou, in the south by a radial 161kV or 225kV transmission line.

With all these developments the West Africa sub region could soon be connected synchronously to form a stronger Power Pool. An expanded harmonized AFLS scheme with all participating utilities in such a pool will be essential to power supply stability and reliability in the sub-region. This practice will be similar to what pertains in Europe.

In the European Continent, including United Kingdom and Ireland a coordinated frequency load-shedding scheme is in place. The load –shedding is coordinated such that each participating utility contributes proportionally to any deficit in the interconnected network.

5. CONCLUSION

From the above discussion, it can be concluded that the harmonized AFLS scheme has resulted in a more stable and reliable power system to the participating utilities. It has improved the performance of the tie-line between Ghana and la Cote d'Ivoire and reduced its downtime quite significantly.

It has also reduced under-frequency related outages of thermal generators in the interconnected system with an improvement in the performance of the system. Consequently, it has reduced operating costs of the participating utilities hence an increased return on Investment.

In Ghana in particular the AFLS scheme has been able to prevent system collapses so far.

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