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Resolving the incredible Nigerian National Power Grid Collapse Frequency through Reliable SCADA/EMS Deployment

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ABSTRACT

Over an eighteen year period, beginning from year 2000, the Nigerian electricity power grid incredibly collapsed both partially or totally for five hundred and forty six (546) times. This collapse frequency is due majorly to the lack of a functional and reliable SCADA system that usually perceives disturbances and employs mitigating actions. The current SCADA system in use by the Nigerian grid Controllers is plagued by poor communication infrastructure, analogue substations, rigidity of the SCADA system itself as well as inefficiency of the user and maintenance departments to drive a system they barely know about. This research points out these limiting factors that have inhibited the viability of the system and consequently the lack of visibility of remote substations by the National Control Centre (NCC), a situation which has accordingly amplified grid management challenges. The research has therefore advised a solution based procurement approach smart enough to train TCN staff sufficiently, deploy a survivable and resilient communication backbone, automate power stations and modularly but incrementally deploy a new SCADA/EMS for easy integration, maintainability and sustainability.

Key Words: ***Nigerian National Power Grid, Grid Collapse, SCADA, EMS***

1. Introduction

Electricity is an essential ingredient for national development. With electrical energy, the people are capacitated to work from the domestic level and the camp industries, through the small-scale and medium industries to employment in the large-scale manufacturing complexes. Arguably, quality and affordable electricity is clearly the insufficient social-economic catalyst required to propel Nigeria's dwindling economy, enhance employment and alleviate crime. The Nigerian power grid however, collapses indiscriminately due largely to the lack of a reliable SCADA/EMS. Previous SCADA/EMS deployments failed chiefly because of the deployment approaches. However, adopting a solution based procurement strategy will ensure the reliability and sustainability of the new SCADA/EMS to be deployed. With a reliable SCADA/EMS, the Grid Controllers can have the vision required to perceive system disturbances and accordingly apply mitigating actions.

2. Fairy Tale of the Incredible Nigerian Power Grid

An electric power grid is a network of interconnected power systems for delivering power from Producers to Consumers. The collapse of the grid means loss of power supply across the environments/customers that the grid supplies. This is otherwise referred to as voltage collapse. Grid collapse is an unacceptable situation that warrants setting up of investigative panels whose findings ensure recommendations of possible solutions meant to avoid future occurrences. However, this is not the case with the Nigerian National grid. The epileptic grid collapses indiscriminately. Being managed by the Independent System Operator (ISO) and maintained by the Transmission Service Provider (TSP), both subsidiaries are managed by the Transmission Company of Nigeria (TCN). The grid lacks a reliable SCADA system necessary to provide the vision grid Controllers require to manage it efficiently. Available literature demonstrates that over an eighteen year period, beginning from year 2000, the grid had collapsed for an unthinkable combined total of five hundred and forty six (546) times. This figure demonstrates a partial collapse of two hundred and forty one (241) times and a total collapse of three hundred and five (305) times. Table 1 shows the frequency of annual grid collapse over this eighteen year period [6][13].

Table 1: Annual Nigerian Grid collapse frequency from year 2000-2018

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Partial Collapse	6	5	32	39	30	15	10	8	16	20	20	6	8	2	4	4	6	9	1
Total Collapse	5	14	9	14	22	21	20	18	26	19	22	13	16	22	9	6	22	15	12
Total	11	19	41	53	52	36	30	26	42	39	42	19	24	24	13	10	28	24	13

Even though, these collapses are frequently attributed to Faults, overload, or frequency, the excuses seem to be normal occurrences in any Power system. However, with reliable SCADA systems, these contingencies are perceived, viewed and mitigation actions are taken quickly enough to restore normalcy/stability to the system. A plot of the system collapse plaque over time depicted in figures 1 and 2 show that the rampant situation doesn't seem to be healing anytime soon. The available statistics has insinuated that averagely, the grid alarmingly collapsed both partially or totally about two and a half times every month over the eighteen year period. In fact, In January, 2018, the grid collapsed six (6) times within eight days [1][9][11]. This left the entire nation in darkness and dependent hospitals stranded. As a matter of fact, hospitals that depended entirely on public supply or otherwise experienced faulty diesel power generators lost patients who were only aided by life support machines. This frequent power outage inhibits research and consequently, produces a daunting effect on the nation's technical know-how.

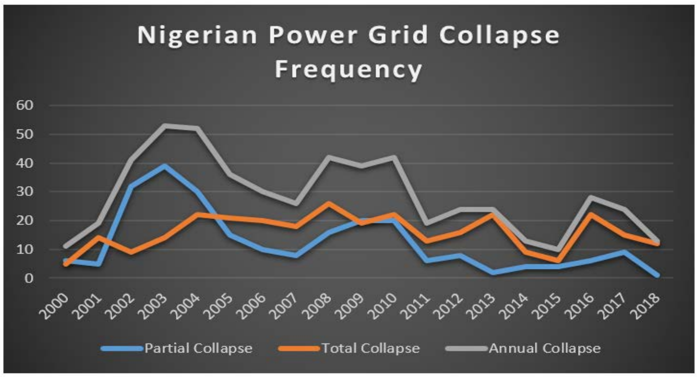

Figure 1: Annual Partial and Total collapse Frequency

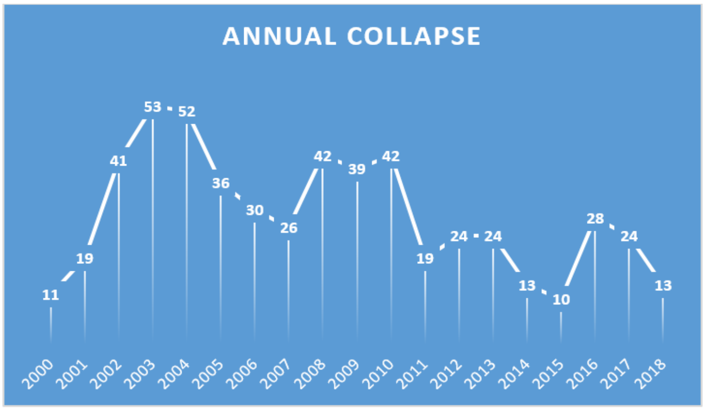

Figure 2: Annual Grid collapse frequency plot from year 2000-2018

Even though Researchers like Samuel et al [4] recommended the New Line Stability Indices (NLSI-1) for Nigerian power Grid collapse prediction, such recommendations can only attempt to alleviate the collapse frequency but not provide the desired stability and security since such methods will still not provide the vision the grid Controller desires to supervise the entire network.

3. SCADA and Power Systems

SCADA is an acronym for Supervisory, Control and Data Acquisition. It is a technology that acquires real time data from field equipment for the purpose of supervision, control and analysis of power systems and associated field elements. The Control centre takes advantage of acquired data for informed and prompt decision making. When SCADA is fused with an Energy Management System (EMS), the system further enjoys benefits like outage planning, load forecast, contingency analysis, generation Unit Scheduling and commitment, market settlements, etc. The SCADA/EMS may therefore be considered the Power System's 'brain' responsible for the efficient management and operation of interconnected systems within the Grid.

4. History of TCN SCADA/EMS

SCADA got its debut in the Nigerian Power sector with the DASA project of 1978 to 1982 under the then NEPA. The project involved the supply, installation, adaptation and commissioning of SCADA and substation RTUs. It was executed by Messrs Brown Boveri of Switzerland. However, due to low performance, an In house DASA Reactivation taskforce (1990 to 1994) was set up to review the DASA project and counsel on the way forward regarding the areas of failure.

While the DASA reactivation was going on, a new computerised SCADA was being implemented for Shiroro Area Control (Shiroro area Control SCADA (1991 to 1995)). The scope of the project included the Design, supply, installation, adaptation and commissioning of SCADA and seven RTUs and telecommunication equipment in the substations of Shiroro Area Control Centre (ACC) Complex by Messrs. Siemens AG. In recognition of their success with the Shiroro Area Control SCADA, the Supplementary National Control Centre (SNCC) SCADA project (1995 to 2000) that deployed Computerized SCADA project for Supplementary National Control Centre in Shiroro was awarded to this same Vendor. However, this will eventually give way for a larger scale project (The WB/PMU SCADA project).

The WB/PMU SCADA project followed the exploits of the SNCC Project (1995 to 2000). Computerized SCADA project for NCC, SNCC and additional RCCs in Lagos and Benin was executed by Messrs. Siemens AG. The project involved supply, Installation, adaptation and commissioning of SCADA system and substation RTUs across all existing substations. However, the inglorious nature of this project warranted the SCADA Reactivation Phase 1 (April 2012 to Oct 2013) project. This was the reactivation of the WB/PMU SCADA project awarded to Messrs, Siemens AG for the inspection of equipment in four control centres and RTUs in the substations, recommendation of spare parts required for the rectification of any faults discovered as well as the training of System Operators on usage of the deployed tools. With continually failed foreign options, the next option was the SCADA in house reactivation Phase II (Nov 2013 to Sept.2015) which continued the reactivation of the WB/PMU SCADA through continued reactivation of RTUs in the substations, solving adaptation problems and also carrying out point to point tests between the substations and NCC for the commissioning of the substation RTUs [3]. However, this and more efforts made have not yielded any appreciable result and consequently, the poor state of the SCADA system still plagues the Nigerian grid control.

4.1 The Current SCADA/EMS

The existing SCADA/EMS is a proprietary Energy Management System by SIEMENS with proprietary database and inter application messaging system. This system is vendor lock-in and its deployment was forklift (All in one); hence, compelled TCN to buy all the EMS applications and equipment from this same vendor. Consequently, this has circumscribed TCN's ability to upgrade, modify or change packages to suit the realities of the present day market environment. Although the accompanying packages could meet the then demands of an energy market, modules like the Automated Metre Reader developed in house by TCN or procured for certain functions from vendors rather than SIEMENS cannot be integrated into this system because of the system's proprietary nature. It is even more worrisome that substations built, equipped and automated by vendors like ABB, NARI, GE, etc. cannot be easily integrated into this system without contracting the integration process out to SIEMENS or hiring the extremely special skills of experts who understand both systems. This is due solely to the lock-in nature of the existing system. However, sustainable Energy Management Systems should be flexible and Flexible Energy management Systems should be interoperable. Utilities deploying these systems should be in control of them and should be able to tweak them to meet their needs. The unfriendly nature of this deployed system has therefore annulled the integration objective and consequently hampered expansion and reliability.

It is no-brainer that the current TCN SCADA/EMS and Telecommunication facility have to either be replaced completely or upgraded to meet the current Grid Management demands. Apart from the fact that the system is obsolete and barely serves 30% of the Grid Management requirements, the EMS has hardly ever been used due to unavailability of reliable and real time data of the entire network at the Control Centre. Statistically, according to the daily reports of the National Control Centre (NCC) SCADA department [10], out of the eight (8) Power generation stations, nineteen (19) 330 kV Transmission Substations and one hundred and thirteen (113) 132 kV substations integrated to the system, the grid Controller inconsistently has just about 20% visibility of them. In addition to these problems, the Grid has almost doubled in size since the installation of this SCADA/EMS and Telecoms implementation with about more than twice the number of Power Stations and 330kV substations as well as about one and half times the number of 132kV Transmission Substations in existence today [12]. This therefore implies that the current SCADA system is not a true representation of the network. Figures 3 and 4 depict the inefficiency of the current SCADA system to provide the National Control Centre with the desired visibility to power generation or transmission Substations.

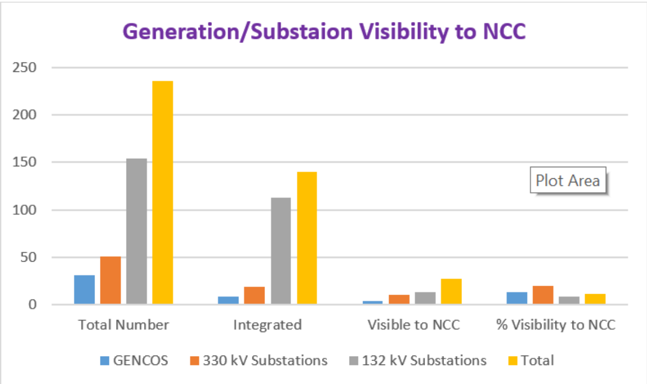

Figure 3: Plot of Substation Integration to SCADA system and Visibility by NCC

As it is evident in figure 3, instead of 100% visibility, only 140 stations have been integrated to the SCADA/EMS. From this figure, NCC experiences just a meagre 12.9% visibility of power plants, 19.6% visibility of 330 kV Transmission stations and an incredible 8.4% visibility of 132 kV Transmission Substations. This implausible capability of the current SCADA/EMS is further seen in figure 4 where the NCC is blind to 88.56% of the high voltage stations on the power grid. Even though 59.3% of the stations have been integrated to the SCADA/EMS, the system struggles to maintain a sustained visibility of 19.29% of these integrated stations at NCC [10][12].

Figure 2 also concurs with the importance of a reliable SCADA/EMS in the Nigerian Power Grid management. In comparison to the history of SCADA deployment, figure 2 demonstrates the reduced number of system collapses from 2005 when the SCADA implementation of the 2004 **WB/PMU SCADA project** began. The improved visibility aided prompt and better decision making. However, as the system got abandoned and aged, the undesired number of system collapse began to rise again until in 2011 when the SCADA reactivation project began. A similar trend is seen with the second phase of the SCADA reactivation project between 2013 and 2015.

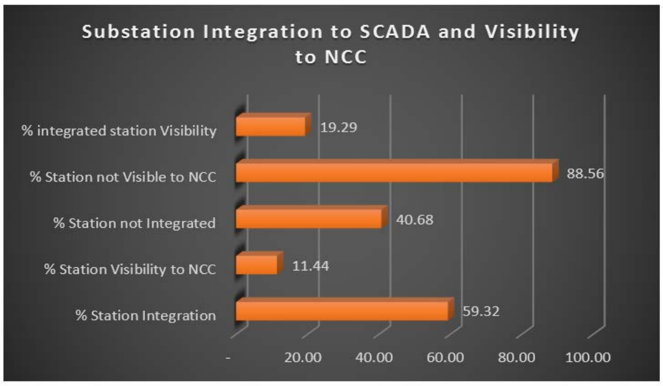

Figure 4: The True Position of SCADA/EMS with regards to the Nigerian Grid Management

4.2 Problems plaguing the current SCADA/EMS

The current TCN SCADA/EMS has centralized data aggregation centres at NCC Oshogbo and SNCC Shiroro. The system consists of various packages like fault analyzers, data historian, Power flow analyzer, contingency analyzer, etc. These various packages are aimed to work in harmony to achieve the key objectives of real time supervision and control of the power system for stability and security as well as data acquisition for system analysis and planning. However, this very appealing objectives are rarely achieved due to the following deficiencies.

I. Communication Infrastructure

The backbone of every successful SCADA/EMS is a sound, reliable and robust communication infrastructure. Field data acquired by Remote Terminal Units and Gateways can only arrive the Control Centre(s) via a reliable communication medium. The reliance of the TCN SCADA/EMS on weak, unreliable, radial, obsolete, insufficient, non-redundant, and in many cases non-interoperable communication equipment has played a giant role in inhibiting the appreciable potentials of the SCADA system. The fibre optics across the network snaps indiscriminately. Installed UHF radios are obsolete hence continually break down or experience attenuation challenges. Installed terminal equipment like PDH, PLC and SDH do not interoperate across vendor boundaries. The still existent but less useful PLCs that are totally analogue require upgrades to digital forms. However, in order to achieve reliability of the SCADA/EMS, the telecommunication infrastructure must first of all be fixed and made reliable. According to CIGRE's Green book on Utility Communication Networks and Services, communication infrastructures should exhibit survivability and resilience. Where Survivability is the ability of the communication service to continue during and after a disturbance (network infrastructure fault), Resilience is the ability to provide and maintain an acceptable level of service in presence of faults [5]. As SCADA/EMS is the brain of the power system, communication is the nerve without which information cannot get to the brain. It is therefore worthy to note that no matter the SCADA system deployed, if TCN fails to maintain a reliable, survivable and resilient communication backbone which interestingly can also serve as a good source of revenue in addition to power, the project can always be considered dead on arrival. The communication infrastructure therefore requires all the attention it desires not only for basic power system operations but also for successful SCADA technology.

II. **Substation Automation**

The **C** in SCADA stands for control. This means if SCADA must assume full functional duties, control of all primary equipment in all substations must be enabled and utilized. However, remote control of these equipment can only be achieved through substation automation. The analogue nature of so many TCN substations has continuously hindered remote equipment control and operation by the grid Controller when the need arises thereby rendering the system vulnerable and dependent on the mercy and quality of skills of the substation Operators who rely absolutely on frequency meters in most cases for actions (to be) taken. To eliminate this deficiency, it is expected that TCN should show full willingness to accommodate a fully functional SCADA system by automating all substations and respectively deploying interoperable Communication Terminal equipment for onward transmission of control and field data to the control centre(s).

III. **Flexibility of the Existing SCADA/EMS**

The existing SCADA/EMS is a proprietary Energy Management System by SIEMENS with proprietary database and inter application messaging system. This system is vendor lock-in and its deployment was forklift (All in one); hence, compelled TCN to buy all the EMS applications and equipment from this same vendor. Consequently, this circumscribed TCN's ability to upgrade, modify or change packages to suit the realities of the present day market environment. Although the accompanying packages could meet the then demands of an energy market, modules like the Automated Metre Reader developed in house by TCN or procured for certain functions from vendors rather than SIEMENS cannot be integrated into this system because of the system's proprietary nature. It is even more worrisome that substations built, equipped and automated by vendors like ABB, NARI, GE, etc. cannot be easily integrated into this system without extremely special skills by experts who understand both systems. This is due solely to the lock-in nature of the existing system. However, sustainable Energy Management Systems should be flexible and Flexible Energy management Systems should be interoperable. Utilities deploying these systems should be in control of them and should be able to tweak them to meet their needs. The unfriendly nature of this deployed system has therefore annulled the integration objective and consequently hampered expansion and reliability.

IV. User Proficiency

This is another glaring deficiency associated with the failure of the existing SCADA/EMS. The user departments as well as the Administrative Engineers are rather in dire need of expertise, proficiency and versatility required to maintain and improve a technology that was dumped upon them. Ideally, they should be experts. However, their lack of involvement at the developmental and deployment stages left them clueless. Hands on trainings that should have improved their capabilities have seldom come and when any, so incomprehensive. For users to efficiently get the best out of any system, they need not only own the system but also decide the future of the system. It is therefore recommendable that subsequently, provision should be made for TCN Engineers from the maintenance and user departments to be actively involved in all the stages of SCADA/EMS deployment. This will not only let them own the system but make decisions that are peculiar with the Nigerian power system as well as transfer their expertise to other staff for continuity at cheaper or in some cases no cost.

5. The Way Forward

The dream for a desired and successful SCADA/EMS implementation begins with a reliable procurement process. To accomplish this, a solution based procurement process which encompasses equipment procurement as well as all the factors that relate with the system to ensure that the desired objectives are met before the project close out should be adopted. This procurement process will recognize and correct the challenges that have plagued the current SCADA/EMS.

While many important requirements must be developed, perhaps one of the earliest to be considered is communications capability and required functionality. While specific features can be scaled to meet future needs and growth, available communications bandwidth needed to support any supplementary features should be taken into consideration upfront. Delivering communication services to operational applications requires not just implementing a suitable telecommunication infrastructure with adequate capacity but also with a high degree of reliability and security. The network must cover all service access points in power stations, control and monitoring platforms and must assure access to and from the technical offices. When very well designed and implemented, other applications like physical access control, video surveillance and metering can leverage the network's robustness and reliability. Moreover, existing legacy systems like radios, antennas, RTUs, fibre and cabling can also be leveraged in order to maximize investment return and reduce upfront costs.

Further on, with about 65 million US Dollars available for the SCADA project [8], TCN must automate analogue Transmission Stations ahead of the procurement process.

Likewise, TCN should adopt a modular system of SCADA deployment, a strategy that can afford them the luxury to replace modules of the SCADA with desired ones, upgrade such modules, modify them or integrate in house developed applications as well as afford them the ability to tweak the SCADA to suit the realities of the Nigerian electricity Market. The modules can be deployed separately and from varying vendors but must be interoperable for easy and quick integration with other modules of the system. This will solve the non-flexible nature of the current system and also eliminate the challenges encountered while dealing with proprietary systems.

Interestingly, by working with an outside engineering team well versed in the latest technologies (Consultants), TCN can reduce complexities and make SCADA a reality. Experienced engineering teams familiar with the latest hardware and software components, as well as the potential challenges with integrating legacy equipment, can help control overall project costs and timing [7]. This implies that TCN should employ the expertise of a consultant vast enough to support the project. However, the training of younger and ambitious Engineers should not be neglected. This training can be captured in the procurement process such that there is knowledge transfer. These younger/ambitious Engineers are assigned the desired EMS modules while working with prospective vendors as Subject Matter Trainees. When very well trained, the said Engineers will develop into subject matter experts and will be responsible for the design and prototyping of operational procedures in line with the Grid Code and operational procedures into the SCADA/EMS system. They will also be responsible for the training and day to day support of the user department staff. In order to be abreast with the technology to come, the Subject matter Trainees should be supported with good knowledge of the power system and what is to come so that if possible, they decide the best way possible for modules to be implemented and prototyped. Generally, the training of staff cannot be overemphasized. The future and maintenance of the system onus lies with the company's staff, therefore if the system must be sustained, adequate training must be made available to maintenance and user department staff.

Once again, in order to integrate and leverage existing legacy systems, the adoption of the Common Information Model (CIM) is important. CIM is an abstract information model used to model electrical networks and various equipment used on them. It was developed to solve the problem of vendor lock-in created by the Energy Management System (EMS) vendors who served the utility marketplace. TCN also possesses a versatile network of power, Communication and SCADA resources from a heterogeneous number of vendors with instruments of varying proprietary communication formats. This has made the number of interfaces between applications grow rapidly due to integration needs. The Common Information Model (CIM) therefore is needed in TCN to solve the challenge of integrating equipment and applications from a myriad of vendors. When the California Independent System Operator (CAISO) had integration challenges similar to what TCN is experiencing at the moment, they leveraged IEC TC57 CIM for the network models and enterprise wide messaging to integrate different applications from different vendors. CAISO also created CIM extensions for different market and grid applications and network models [2]. Many other ISOs like PJM, ERCOT and NYISO make use of the CIM. TCN can therefore leverage this experience.

With regards to the fact that the Nigerian electricity market is now deregulated, TCN through the ISO must enforce compliance with the ruling documents. As such, procurement of SCADA/Communication equipment do not need to cross boundaries. Cabinets should be provided at the Control Centre for GENCOS to service the NCC with data necessary for system operations, failure of which should attract sanctions as the ruling documents may state. This will assist to shed cost as well as facility management responsibilities off TCN.

Table 2 therefore compares the previous SCADA implementation to the recommended implementation.

Table 2: Comparison between the Previous and recommended SCADA/EMS Deployment

S/N	PREVIOUS SCADA PROJECT	RECOMMENDED SCADA PROJECT
1	Implemented under the vertically integrated defunct NEPA/PHCN without consideration to Grid Code, Market Rules and the Electric Power Sector Reform (EPSRA) Act.	Should be Implementation under the deregulated Nigerian Electricity Supply Industry (NESI), the project will therefore be governed by the EPSRA Act, Market Rules, Grid Code and Operating Procedures. Procedures will therefore have to be accommodated in the EMS.
2	Project was equipment based. Equipment were procured with less consideration for training and other factors that could ensure a reliable and sustainable SCADA/EMS	Project should be solution based. Implementation process should consider all factors that can lead to success such as substation readiness, personnel preparation, behavioural and attitudinal issues. Approach would be phased implemented so that previous stages would be completed and tested okay before moving to the next stages
3	Cluelessness of staff involved in the implementation process encouraged the Original Equipment Manufacturer (OEM) to do whatever was convenient for them without due consideration to client needs	Knowledge based SCADA/EMS and Telecommunication Project implementation. TCN should instruct (OEM) on its' desired outcome in line with the technical specifications. Experienced staff and Subject Matter Trainees should decide how EMS modules should function and be maintained.
4	Project was not future proof. This led to expiration of licences, inadequate spare parts, lack of long term maintenance plans/ system upgrades as well as inability to tweak the database	This Strategy considers maintenance, spare parts stocking, data engineering and modification of database, Service Level Agreements (SLA) with OEMs for upgrade of software and in-house development of software/algorithms.
5	No consideration for System Integration	With the use of CIM alongside Service Oriented Architecture (SOA) and Service Enterprise Bus (ESB), integrations can be done with less efforts
6	Deployment was forklift	Deployment should be modular but incremental

CONCLUSION

The Nigerian Power grid collapse frequency is high due to the inability of the SCADA utility to perform optimally. The current SCADA system is inefficient due to poor communication infrastructure, analogue substations, user incompetence and the inflexibility of the system itself. Moreover, the national grid itself has almost doubled in size since the implementation of the current SCADA system. This has consequently increased the number of substations that are not integrated to the SCADA system and as expected, the threshold of those invisible to grid controllers; a situation which has compounded the grid management challenges. The history of previous SCADA/EMS deployments show an equipment based procurement approach that focused more on equipment and so much less on facility acquaintance, awareness and sustainability. However, with funds available, TCN must adopt the solution based procurement approach smart enough to train her staff sufficiently, deploy a survivable and resilient communication backbone, automate power stations and modularly but incrementally deploy a new SCADA/EMS for easy integration, maintainability and sustainability.

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