IMPROVING THE QUALITY OF POWER SUPPLY IN DISTRIBUTION NETWORK USING GENETIC-BASEDSTATIC VAR COMPENSATOR

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ABSTRACT
This paper presents improving the quality of power supply in a distribution network using a genetic-based SVC. The research methodologies used in this study were experimental and simulation approaches. The study focused on the Onuiyi-Nsukka 30 Bus, 7.5MVA, 33/11KV distribution network, which some the bus did not satisfy the requirements of the Nigerian Electricity Regulatory Commission (NERC) of 1.0000pu (+5%). To address this issue, a genetic algorithm was employed to identify all the unstable chromosomes (bus) using a fitness test. The researchers used a 300Mvar rated SVC to stabilize the buses by injecting reactive power from a 94Mvar Thyristor Switched Capacitor (TSC) and absorbing excess reactive power by a 109Mvar Thyristor Controlled Reactor (TCR) when necessary. The system was implemented at the secondary side of the 33/11KV distribution network using the power system toolbox, optimization toolbox, and Simulink. The Simulink model was tested with parameters obtained from the testbed during transient conditions. The results showed that the SVC was able to balance the voltage profile, meeting the NERC requirements for bus stability with an average voltage profile of 1.03859pu.

Keywords: **Power; Static Var Compensation; Genetic Algorithm; Thyristor Control; Reactor; Capacitor**

1. INTRODUCTION

The quality of power supply in Nigeria has remained a major topic of discussion over the past few decades. This discussion has interconnected stakeholders from both the public and private sector to recommend a means to improve the quality and reliability of overall power supply.

Nigerian power sector is made up of generation, transmission and distribution sections respectively. The generation section is responsible for the extraction of the raw materials and convert to energy to generate electricity which is then step up from 11/330KV and transmitted to the grid via the transmission networks. The national grid is the control center from which power is been transmitted to other part of the country and then distributed to local consumers via the distribution network.

Today, it is no longer news that Nigeria power system has dilapidated so badly that the need for urgent transformation is required. In the generation section, synchronous machines employed are old and most of the time goes out of synchronism which results to mechanical transient that impact on the prime movers and power system components. The transmission network on the other hand has long distance between each other which is never good as it gives room for losses, among other challenges. On the distribution network which is privatized by the Nigerian government, the lack of investment on the sector, due to economic and political reason, also ensure that the quality of power received for distribution are not properly managed and compensated before distribution.

The quality of power in this study will focus on the real and reactive power stability. During power transient due to fault, the active or reactive power changes in most cases and requires compensation to restore power system stability (Temerbaev et al., 2014; Kar and Biswajit, 2016; Kumar and Abdul, 2016).

Transient stability analysis has attracted various research attentions over the years. One of the widely used approaches proposed to solve the problem is the use of Flexible AC transmission Systems (FACTS). These are power electronics control systems which have the intelligence to solve the problem of power system imbalance via the injector or absorbance of active or reactive power, depending on the state of the power system (Udeh et al., (2017); Ilo et al., (2019); Sahu and Kamalakanta, (2015); Unnikrishnan(2015)). This approach has achieved great success in maintaining power system stability.

One of the most applied FACTS is the Static Var Compensator (SVC). This system is made of thyristor-controlled capacitor banks and reactors which can inject or absorb reactive power in load flow to ensure power system stability (Unnikrishnan, 2015). However, the need for an optimizer which can enhance the SVC to ensure a holistic identification and optimization of all unstable bus within a power system network remained a challenge.

This paper therefore employed an SVC with artificial intelligent technique for the optimization of the Onuiyi Nsukka 33/11KV distribution network, which its consumers have suffered poor quality of power supply over the past years. The genetic based SVC was developed and used to improve the quality of power supplied to all the buses interconnected in the 11kv network and thus the quality of power supplied to the community will meet the recommended standard by the Nigerian Electricity Regulatory Commission (NERC).

2. METHODOLOGY

The methodologies used for this study is the experimental and simulation methodologies. The experimental method was used for the technical investigation to identify the buses which falls below the standard of voltage stability margin for correction. The approach was also used for the system integration after the new solution was developed. The simulation approach was another method used for the research implementation. This was used to implement the genetic based SVC on the 33/11KV distribution network and then tested, before integration on the characterized transformer.

Project Requirements

The requirements are grouped into two categories which are the user requirements and the system requirements. The system requirement was the satisfaction of the voltage stability standard provided by the Nigerian Electricity Regulatory Commission (NERC) standard for power system stability analysis which is 1.00000pu (±5%). The user requirements are to provide optimal quality of power supply at all times.

3. MODELING OF THE ONUIYI 33/11KV DISTRIBUTION NETWORK

The 7.5MVA, 50Hz, Onuiyi Nsukka 33/11 KV distribution network is made up of 30 buses. The single line model of the distribution network which showed how the 11KV incoming from the injection substation was distributed to the various bus are presented in Figure 1.

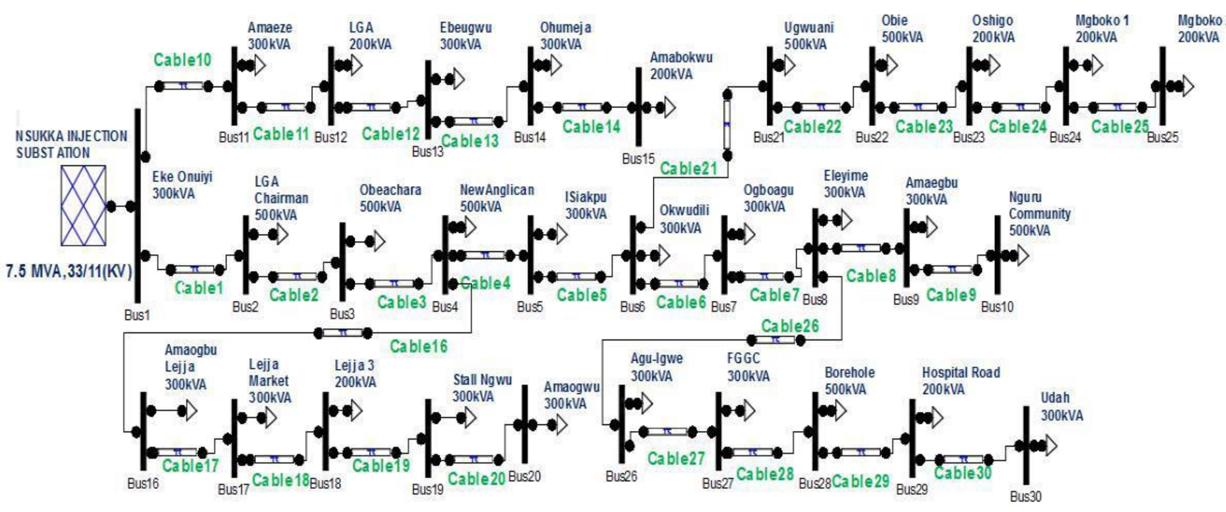

Figure 1: Single line Model of the 33/11KV distribution network (Source: EEDC Nsukka).

4. DEVELOPING A POWER QUALITY OPTIMIZATION MODEL USING GENETIC BASED-SVC

To model the genetic based SVC, first the model of the SVC was developed and then optimized with genetic algorithm to achieve the genetic based SVC for improvement of quality of power supplied.

4.1 Development of the SVC

The SVC model was adopted from Habibur et al. (2013) and then optimize with genetic algorithm to achieve the new SVC model. The capacity of the SVC used in this research was 300Mvar, which regulates voltage on a 33KV distribution system. The SVC was made up of three 94MVar thyristor switch capacitors and one 109Mvar thyristor reactor bank respectively. These devices were connected to the secondary side of the distribution transformer and used for the voltage stability of the distribution network. The Thyristor Switched Capacitor (TCS) operated to inject reactive power from the rage of 0 to 282Mvar capacitive reactive power. The reactor on the other hand controls power variation from 0 to 109Mvar inductive.

The SVC is a power control system which injects or absorbs reactive power to the power flow to maintain stability during imbalance. The SVC used shunt susceptance to inject the reactive power into the power system to ensure stability of the bus. In other cases when the reactive power is in excess, the SVC absorbs reactive power using a capacitor Thyristor Controlled Reactor (TCR) system. The firing angle of the thyristor varies between 90 and 180degrees based on the voltage of the capacitor. The inductive power is Q_{ind}; Q_{cap} is the reactive power, Q_{net} is the desired power. The magnitude of reactive power injected into the capacitor is controlled by the magnitude of reactive power which is absorbed by the thyristor. The SVC can be operated in two modes which are the VAR control model in which the susceptance is maintained constant or the voltage regulation model. The approach adopted for the operation of the SVC in this research was the VAR control technique. In this process of power flow shunt reactor and capacitor banks are used for the voltage control, thus keeping the B constant as shown in the V-I characteristics curve in figure 2;

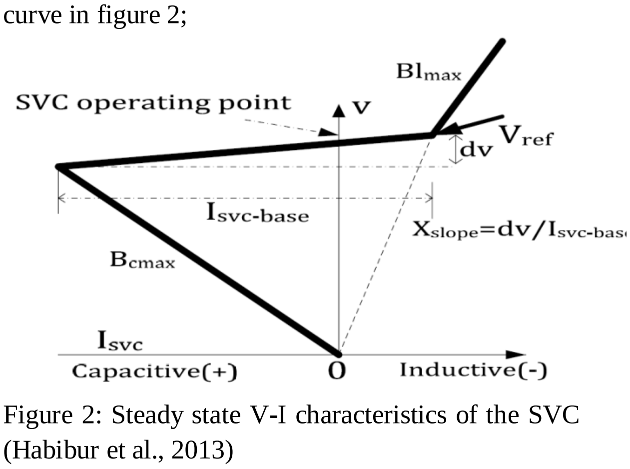

Figure 2: Steady state V-I characteristics of the SVC (Habibur et al., 2013)

Where B is susceptance, V is the voltage; I is current. From the Figure 2, the following presents the voltage regulation range (Habibur et al., 2013);

$$V = V_{ref} + X_s . I \; (-Bc_{max} < B < Bc_{max.}) \qquad 1$$

$V = \frac{I}{Bc_{max}}$: When the SVC is at full capacitive mode $(B = Bc_{max})$

$V = \frac{I}{BI_{max}}$: When the SVC is at full inductive mode $(B = BI_{max})$.(Habibur et al., 2013)

The optimization algorithm which was used to guide performance of the TCS and TCR was achieved with genetic algorithm. The idea was to ensure that the triggering of the thyristors was intelligently controlled as the conventional system lacked this feature. To achieve this, the genetic algorithm was employed which is an artificial intelligence specialized in solving complex optimization problems like this case. To this end the algorithm was used to develop an objective function based on fitness values obtained with reference power factor based on the NERC standard for voltage stability. The model for the fitness test was presented in equation 2;

$$Ft = \frac{x_i}{\sum_{k=1}^{n} fitness(x_k)} \qquad 2$$

Where x_i is the relationship between the active and reactive power , x_k is the voltage profile of the bus, n is the total number of buses at the bus.

4.2 The Genetic Pseudo code for the VAR Control

1. *Start*
2. *Identify all the chromosomes (N) % All bus of the 33/11KV*
3. *Initialize the fitness function % equation 2*
4. *Set reference voltage magnitude (x_i = ≤0.9750pu) % Peak tolerable voltage(pu)*
5. *Identify chromosomes which did not satisfy the x_i % Unstable bus*
6. *Cross over in pairs*
7. *Mutation*
8. *Get the next set of bus with poor power factor*
9. *Return to step (3)*
10. *Do*
11. *Until x_i = ≤ 0.9499(pu) for all N.*
12. *Trigger TSC*
13. *End Do*
14. *If*
15. *Step (5) = x_i = ≥ 1.051(pu) for all N.*
16. *Trigger TCR*
17. *Return to step (3)*
18. *End*

4.3 The flow chart of Genetic Based SVC

Figure 3 below presented how the genetic algorithm was used to compute number of chromosomes within the Onuiyi 33/11KV distribution network and identified buses which were unstable for compensation. The bus voltage profiles which were below the NERC requirements were stabilized via the firing of the TSC band to inject reactive power. On the other hand, when the bus voltage profile was above the standard requirements, the TCR was used to absorb the excess reactive power and stabilize the voltage profile.

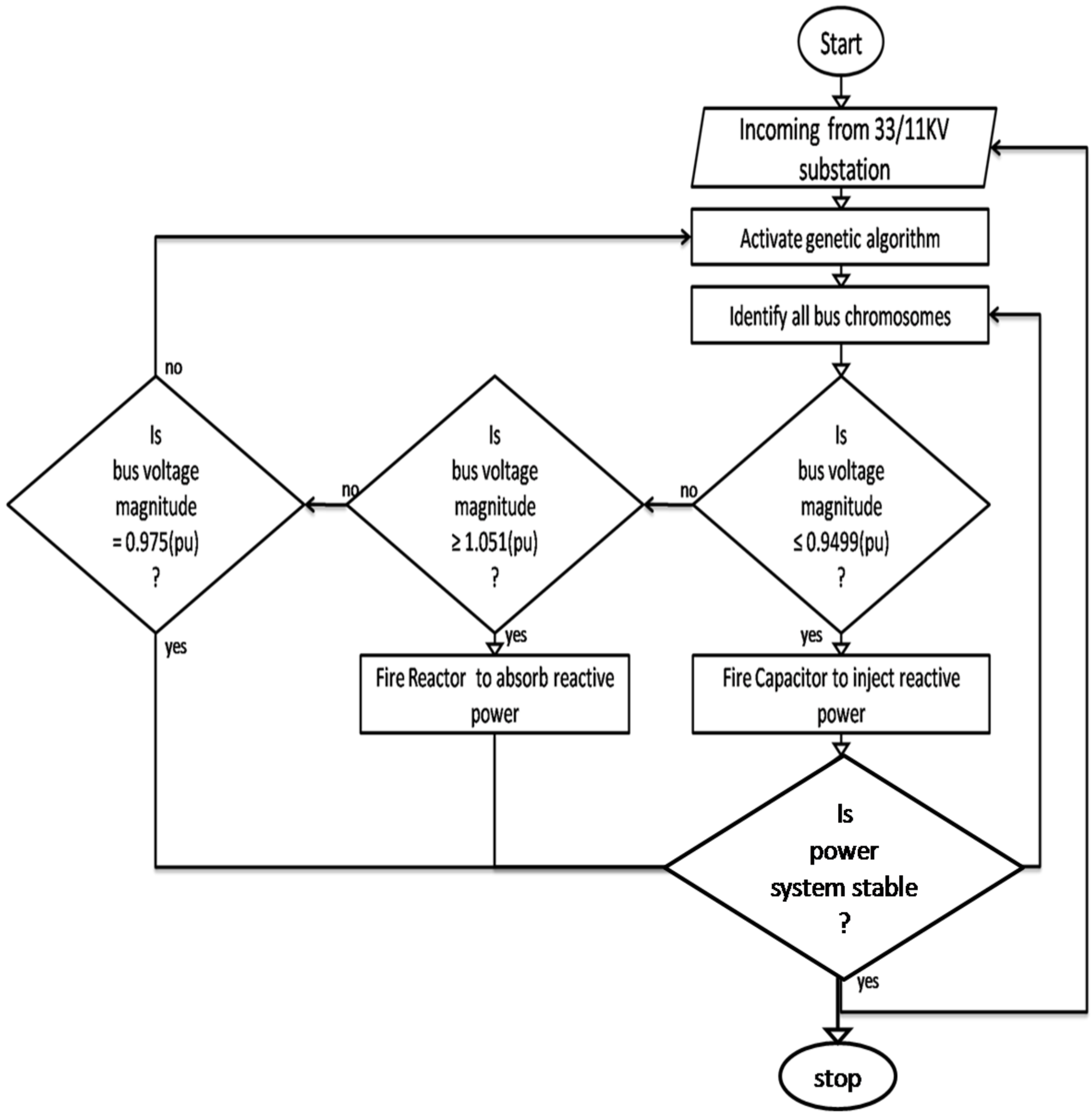

Figure 3: Flowchart of the genetic based SVC

3.5 System Integration

The genetic based SVC was integrated into the distribution network for the stability of voltage profile in the distribution network via the injection or absorption of reactive power from the power system. The equivalent electrical circuit diagram which showed how the SVC was integrated into the power system network was presented in the Figure 4.

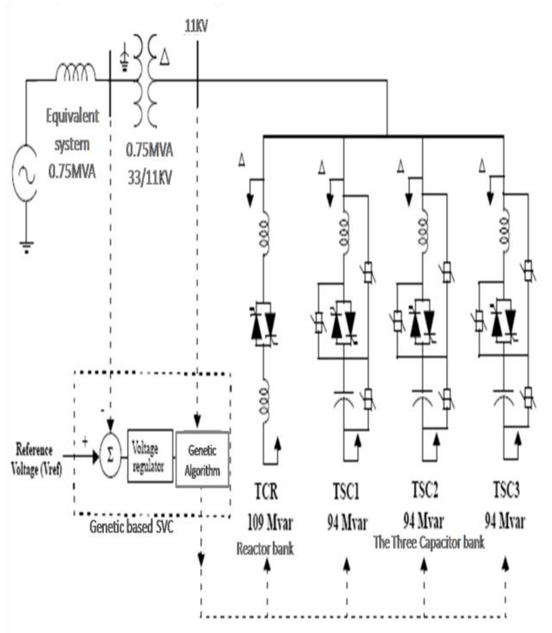

Figure 4: Model of the system integration

4. SYSTEM IMPLEMENTATION AND SIMULATION

The system implementation was achieved using simulation method. The models developed were used to configure the equivalent tools in MATLAB and used for the system implementation. The SVC developed with the TSC and TCR were connected to the power system network characterized using power system toolbox and global optimization toolbox. The power system toolbox was used to model the distribution network, while the optimization toolbox was used to model the genetic algorithm which was used to optimize the SVC performance. The Figure 5 presented the Simulink model of the power system network with the genetic based SVC.

It showed how the incoming of the 33/11KV power system distribution network was monitored by the SVC and stabilize during instability. The equivalent electrical diagram which showed how the three TCS were connected to the three phase of the distribution network was presented in Figure 6, while the transfer function which showed how the SVC model was connected to the network (i.e, the three TCS and TCR) was presented in the Figure 7;

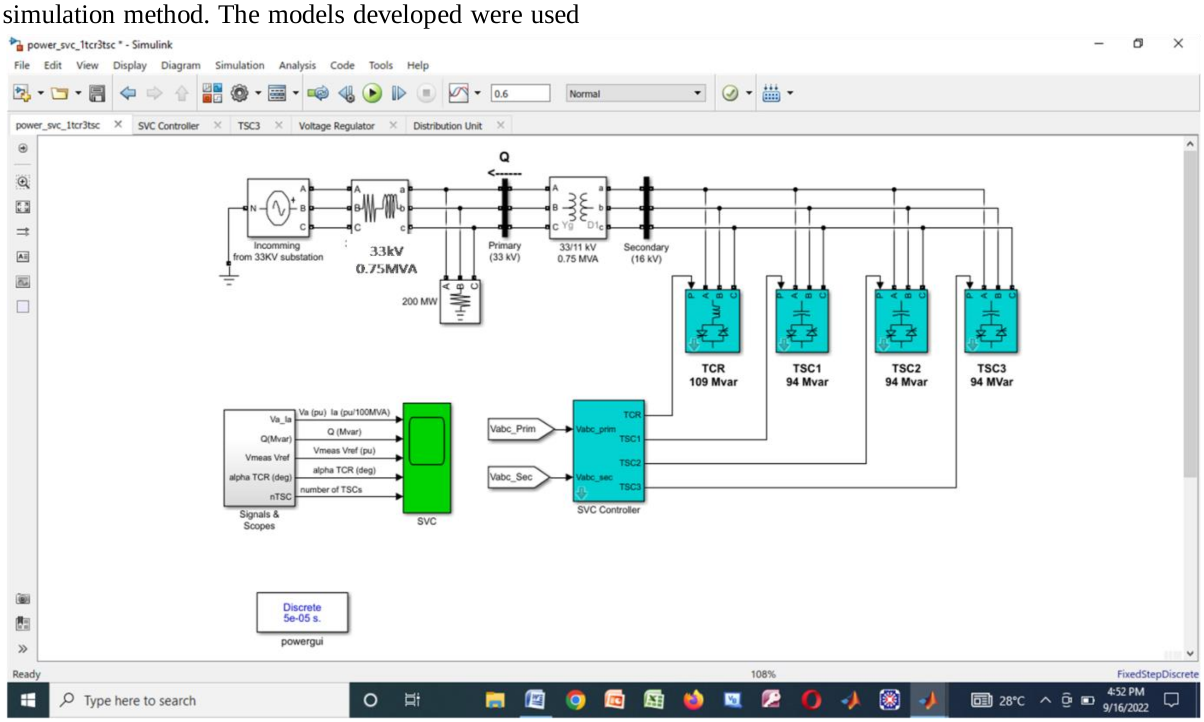

Figure 5: The Simulink model of the power system network with SVC

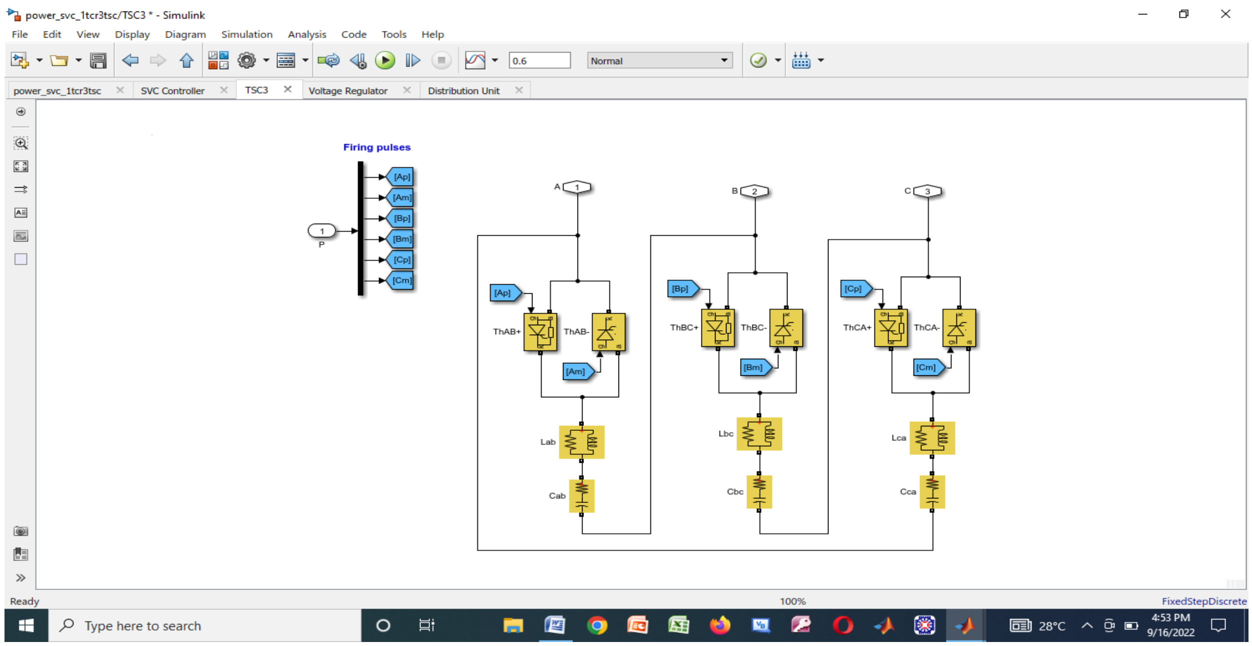

Figure 6: The electrical circuit o the interconnected TSC

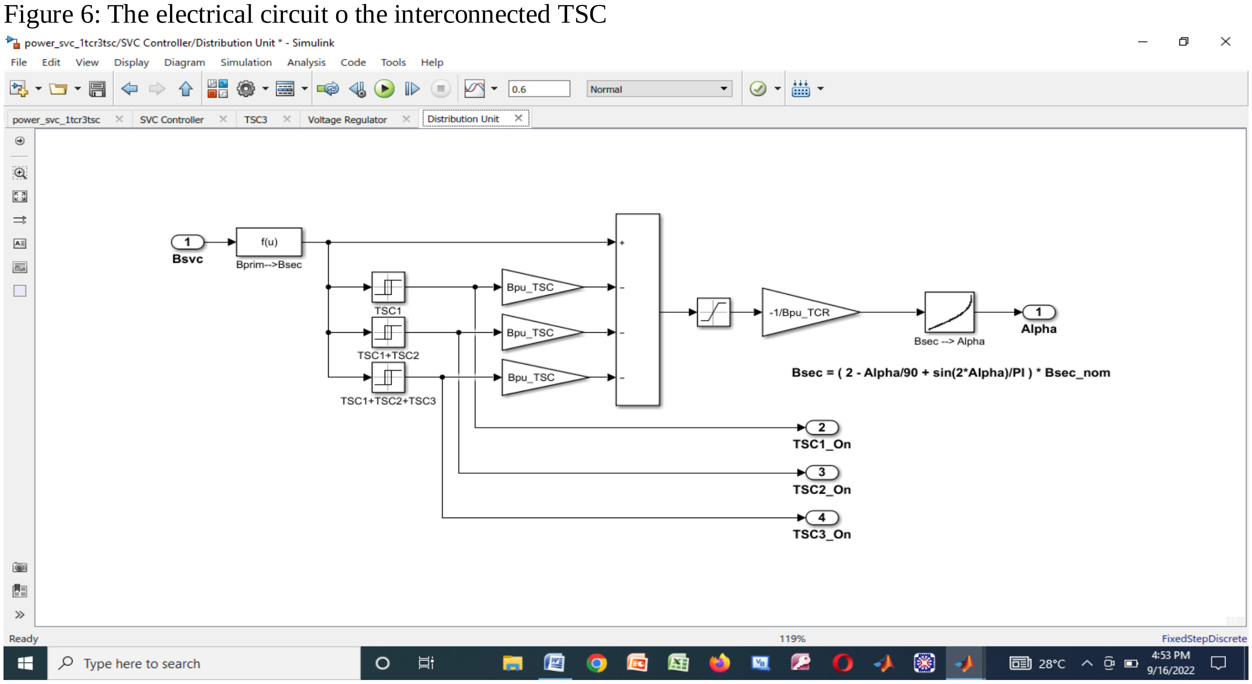

Figure 7: The transfer function model of the SVC

The Figure 7 presented the mathematical transfer function of the SVC in time domain which showed how the TSC were connected to each of the three phases of the distribution network. The model also showed how a buffer gate was connected to each of the TSC to help coordinate the logical performance and ensure harmony during the firing process. The Simulink model was simulated using the parameters obtained from the distribution network characterized at Nsukka and the data were reported in the Table 1.

Table 1: Simulation Parameters

Parameters	Values
Transformer rating	0.75MVA, 33/11KV
SVC capacity	300Mvar
TSC capacity	94Mvar
TCR capacity	109Mvar
Max TCR control	109Mvar
Max of three TCS reactive power	282Mar
Number of buses	30
Frequency	50Hz

5. RESULTS AND DISCUSSION

In the simulation of the distribution network, 2 buses were considered, with transient introduced for bus 1 at initial state and then at 0.4s. The reason was to give room for the assessment of SVC impact during transient and show how the TCS or TCR was used to control the instability. Figure 8 presented the power system network with instability in bus 1.

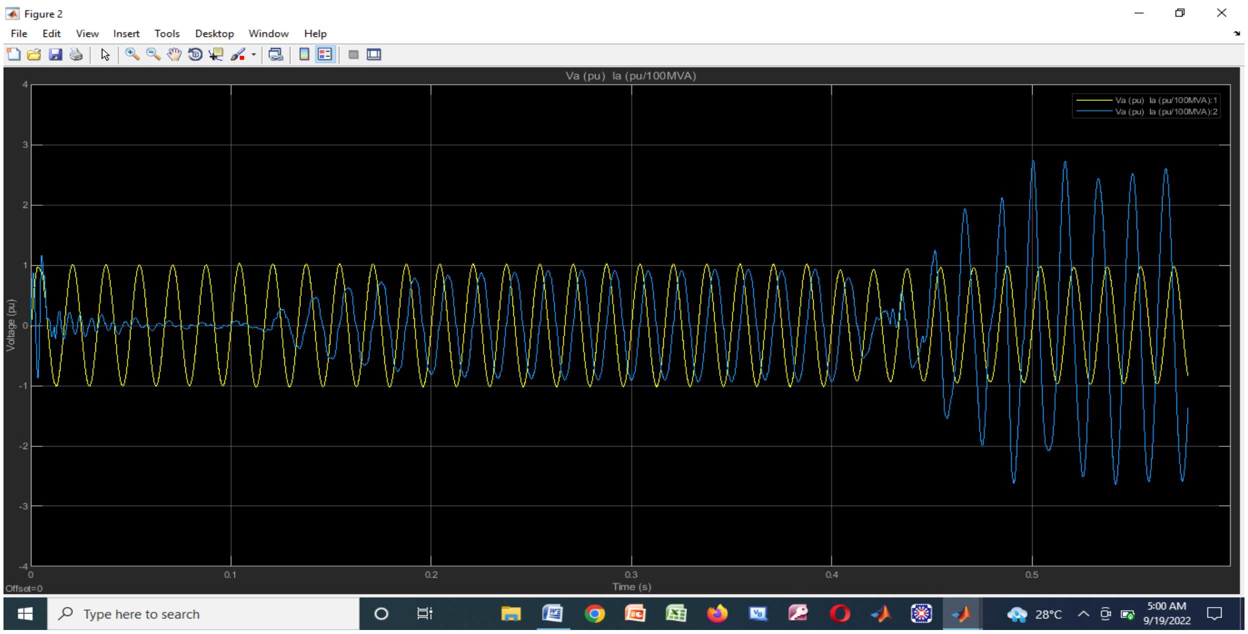

Figure 8: The power system distribution network under transient

The figure 8 presented the power network when simulated with transient at the bus 1 (blue). From the result it was observed that at the initial state, the bus was unstable but was corrected after 0.12s by the SVC until at 0.41s when there is another transient on the bus. The Figure 9 presented the action of the SVC during the transient condition.

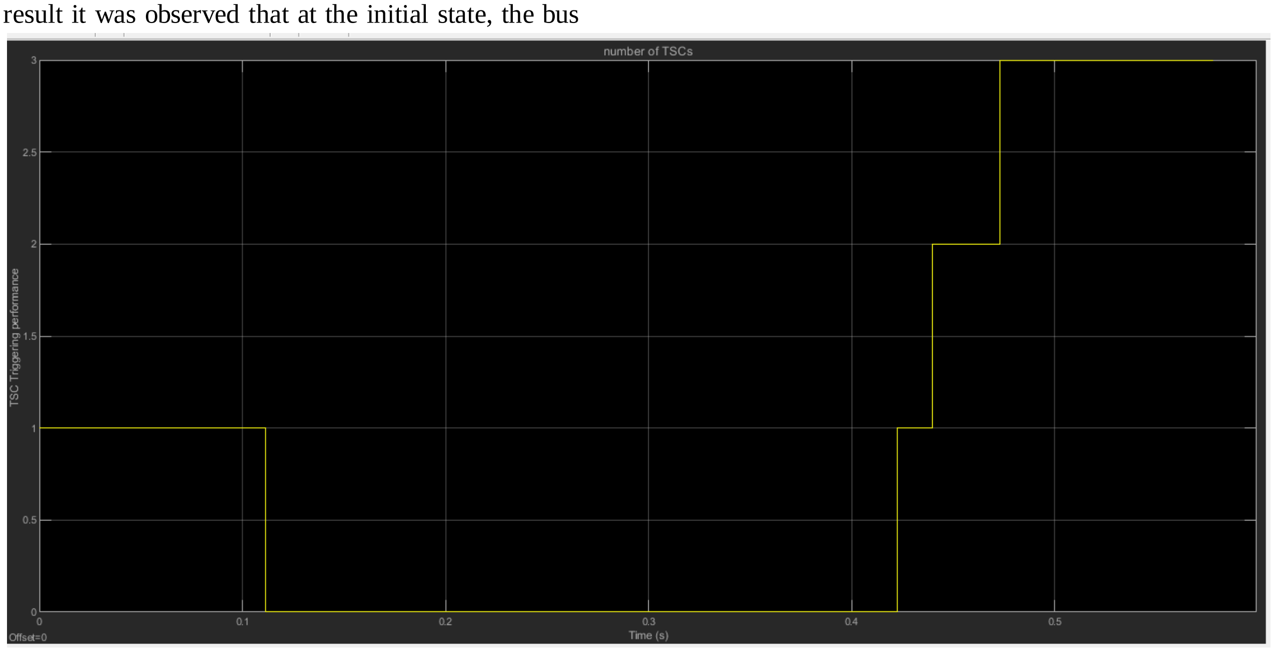

Figure 9: The Genetic based SVC performance

From the Figure 9, it was observed that the genetic algorithm was used to identify the bus chromosomes which do not pass the fitness requirements. In the initial state, due to the low magnitude of the transient, only the TSC 1 was fired to inject reactive power into the network and at 0.12s, steady state was obtained.

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At 0.41s when higher magnitude of transient was introduced, the three TCS were triggered to inject reactive power which controlled the instability. Figure 10 presented the result of the reactive power injection during the transient period.

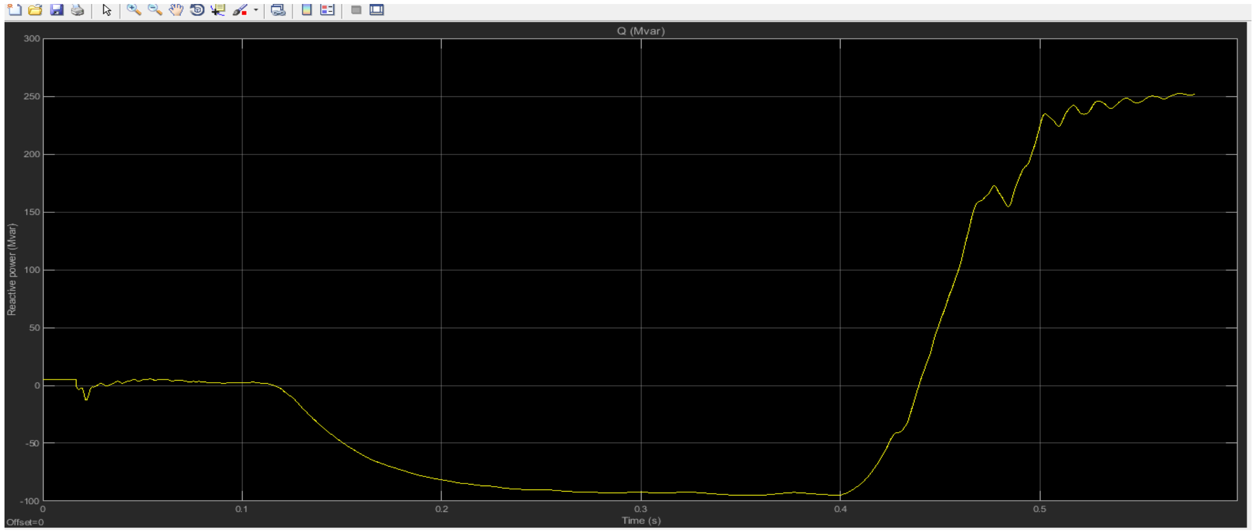

Figure 10: Reactive power injection performance of the SVC

The Figure 10 presented how the voltage was controlled via the injection of reactive power during the period of instability for balancing. The result showed that at the initial state of instability, the TSC1 injected 10Mvar of reactive power to stabilize the bus. Then at the second time of instability which is 0.41s, the three TSC were used to inject reactive power of 250Mvar and then the bus was stabilized. The Figure 11 presented the voltage profile of the bus to show how the Genetic based SVC was able to detect the instability and improve the bus profile to hence improve quality of power supply.

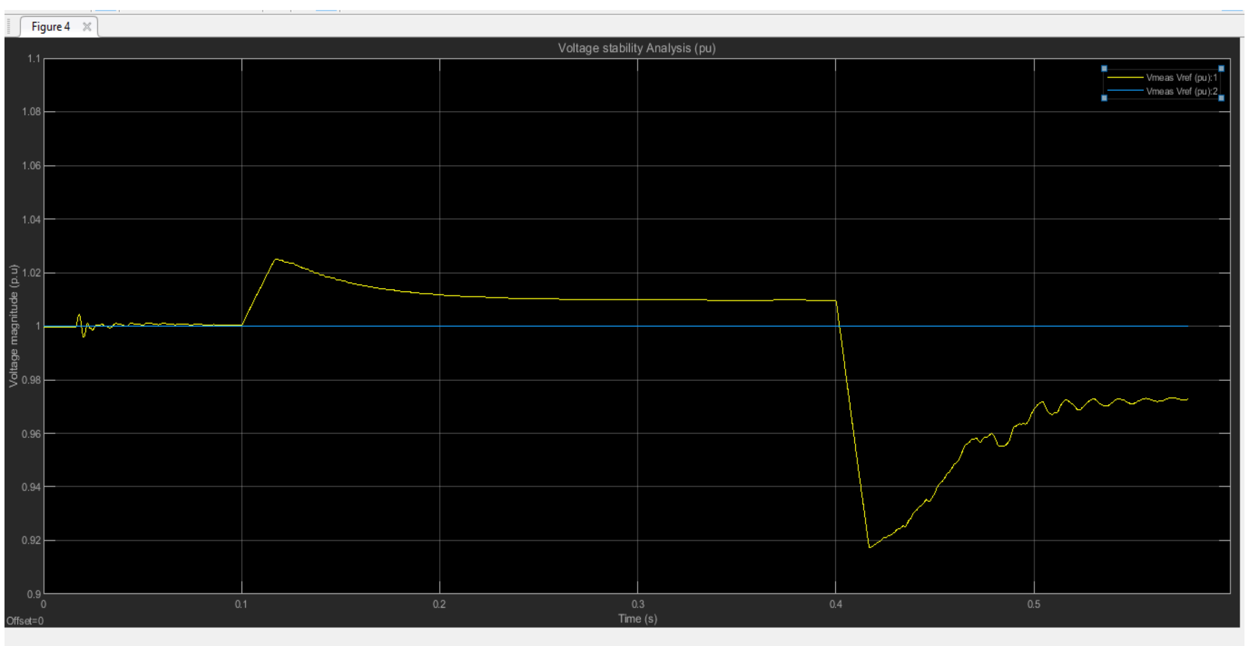

Figure 11: Result of the voltage profile with Genetic based-SVC

The Figure 11 presented the performance of the bus during the instability period. The result showed that the SVC was able to maintain stable voltage profile during minor instability condition which ensures that the bus was stable all through, however at the point of major transient condition which was at 0.42s, the voltage profile dropped to 0.9200pu, but the triggering of the TSC to inject reactive power gradually improved the bus stability until its returned to stable margin of 0.97782pu which satisfied the NERC standard requirements

6. CONCLUSION

This paper presents improving the quality of power system distribution system during transient condition using intelligent SVC. The research focused on transient stability control which can occur due to abnormality in the reactive power rate during load flow. To solve the problem, intelligent SVC was developed using genetic algorithm. The goal was to develop a system which intelligently detect the optimization problem due to transient and then correct the voltage stability margin using SVC. The system was implemented and tested via simulation approach. The result showed that with the improved SVC, the voltage stability was maintained to satisfy the NERC requirements and quality of service was improved with 16.72%.

7. RECOMMENDATION FOR FUTURE

1. Investigate the long-term effects of using SVCs on power network stability and overall system efficiency. This could involve conducting a cost-benefit analysis to evaluate the economic feasibility of SVCs and other reactive power compensation techniques in improving the quality of power supply.
2. Explore the possibility of using hybrid optimization algorithms, such as a combination of genetic algorithms and particle swarm optimization, to identify unstable buses and optimize the settings of SVCs and other reactive power devices.
3. Investigate the use of advanced machine learning algorithms, such as deep learning neural networks, to predict voltage instability and proactively control SVCs and other reactive power devices in real-time.
4. Develop new and more accurate voltage stability indices that can accurately predict voltage instability and provide a more comprehensive assessment of power network stability.
5. Test the performance of SVCs and other reactive power compensation devices under different network conditions, including changes in load demand and renewable energy integration, to evaluate their effectiveness in maintaining power network stability.

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