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Design of Static Var Compensator (SVC) for Improving Power Supply of Solar Energy Connected to the Grid

Marie Grâce Berwa
African Centre of Excellence in
Energy for Sustainable Development
University of Rwanda
Kigali, Rwanda
berwamariegrace@gmail.com

Peter Musau Moses
Department of Electrical and
Information Engineering
University of Nairobi
Nairobi, Kenya
pemosmusa@uonbi.ac.ke

***Abstract*—Development of renewable energy technologies has increased worldwide. Power systems, underneath intensely loaded situations, are at ultra-hazards of credible line outage and consequent voltage unreliability problem. Real power drop and voltage divergence minimization are measures of voltage security of power system grids. The work recommends the optimal usage of the SVC in the enhancement of the voltage stability. Promoting renewable energies has benefits not only for the environment but also for the economic conditions of the country. The challenging of voltage collapse has been expressed as an optimization problem based on the process of particle swarm optimization (PSO), applied in the study of voltage stability of a power system. The success of the projected algorithm confirmed in IEEE-14 Bus standard test system.**

***Index Terms*—Power System, Voltage Stability, Particle Swarm Optimization (PSO), SVC.**

I. INTRODUCTION

Nowadays, the world is developing energy sources other than fuel fossil and gas to mitigate the global warming that is affecting health of the population, the cloud weather, water pollution, animals as well as vegetation. The photovoltaic (PV) energy is an attractive renewable energy with an abundance in sunlight worldwide and its use has increased to 7 percent in 2017. It is expected to reach 23% in the year 2040 [1].Contrary to other renewable energy sources like wind power, the distribution of photo-voltaic power is easily integrated into the electrical network at any point.

PV power systems are mainly grouped in stand-alone and grid-connected systems. A PV grid-connected comprises the PV array, DC-DC converter(s), inverter(s), meters, grid connection as well as DC and AC cabling. The inverters are the most important elements for the integration.

Presently, the grid has settings that can be used to switch voltage and brand the grid steadier; the innovative inverters devices change DC solar power to AC power. In spite of replacing load parameters, as well as want to supply and also engross reactive power in the case of reactive loads, the inverters are vital to supplying continuous frequency and voltage. A PV installation's yield reliant on the reliability and the inverter's efficiency by the way of orientation, interconnection as well as the quality of PV modules. Notable challenges affecting the system of integration include voltage instability, frequency instability, and general power quality. In solar energy the two deviations are the main challenges in grid integration; voltage and frequency are not constant due to the quantity of irradiance.

The Static Volt-Ampere Reactive Compensator (SVC) needs reactors to absorb VARs from the system, dropping the voltage of the system if the reactive load of the power system is capacitive (leading). Below lagging (inductive) situations, the capacitor banks are automatically switched in, thus providing a higher system voltage [2]. To control system voltages, recover transient stability, upsurge transmission capacity, etc. the SVC's are suitable.

Contribution: For the first time, this paper presents the application of SVC with shunt control in the mitigation of PQ issues with increased solar integration to the power grid. A multi objective approach including the location and sizing of the SVC is employed. Simulation is done using Particle Swarm Optimization (PSO).

Paper Organization: The rest of the paper is organized as follows: Section II gives Literature Review, Section III is the Proposed Methodology, Section IV is Problem Formulation, Section V is the Presentation of Results and Analysis, while Section VI is the Conclusion and finally, there is a list of references used.

II. LITERATURE REVIEW

A. Power Supply Problems in PV System Integration

Many attentions required for the integration of solar energy to grid such as solar module manufacturing, connections, and operation among others. The solar energy needs to be unified efficiently on the transmission grid; such interconnection considering the belongings of the grid at numerous facts. Photovoltaic plant encompasses different elements but the very important element for integration is the inverter [1].The main function of an inverter is to invert the direct output to

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alternating current, which makes typically use by different devices. The inverters play essential role in supplying steady voltage and frequency, in spite of exchanging load conditions, and need to supply, alternatively reactive loads absorbing reactive power.

Integration of PV power to national distribution grids causes negative effects on its power quality, its reliability as well as the stability of the electricity network. Another impact is related to the bidirectional power flow from the protection of the equipment issues. From the design of the circuit, with the electrical installation position, have some impact on the voltage changes, network steadiness, voltage control, power quality and safety as well as harmonization. Contrary to conventional power plants, PV power plants lack rotor, therefore no inertia is present; the out power is highly solar radiation dependent. Any prompt fluctuation in solar radiation will cause changes in output power variations. For instance, during sunrise the PV output power increases rapidly and considerably. There is a possibility of reaching the maximum power in short period depending on the rise change of the inverters. Additionally, the change may result from the weather conditions in the vicinity of PV plants.

Finally, the absence of system voltage and frequency, power quality is deteriorated. Also compared to synchronous generators, the PV installations have no issues related to reconnection because they do not need synchronization. Once a fault is detected at network node that is connected to both network and PV generation, the breaker from the network opens to solve the faults. The challenges associated to PV integration vary from one power system to another based on the PV input intensity compared to the power system and their respective topography.

B. Static Var Compensator Description

The SVC controls voltage terminals by monitoring the quantity of injected reactive power into or consumed along the power system. When the system voltage is high, the SVC produces reactive power (SVC capacitive), on the contrast it absorbs reactive power (SVC inductive) [2]. Fast response, extensive operational range and high reliability are the most characteristics of a Static Var Compensator device. To produce and regulate reactive power, the thyristor valves are required practically in combination with capacitor and reactor banks from several methods. The key function of the SVC is to control the voltage at desired bus in monitoring the injected reactive power at that particular point. It is very suitable to maintain or to keep the levels of esteemed voltage for functioning and using loads. In a simple system, the SVC contains a thyristor-controlled reactor, mounted in parallel with a capacitors' bank [3].

The SVC's schematic design is shown as shunt-connected device in figure 1, comprising TCR and TSCs. The SVC is an automated device aimed at bringing the power factor of the system closer to unity [2]. Additionally, SVC experience parallel connection with line and central role is controlling the voltage at a particular bus by regulating its corresponding reactance. SVCs can be used in two main cases, i.e when is connected to the power system for regulating the transmission voltage ("Transmission SVC") and when is connected near large industrial loads for improving the power quality ("Industrial SVC").

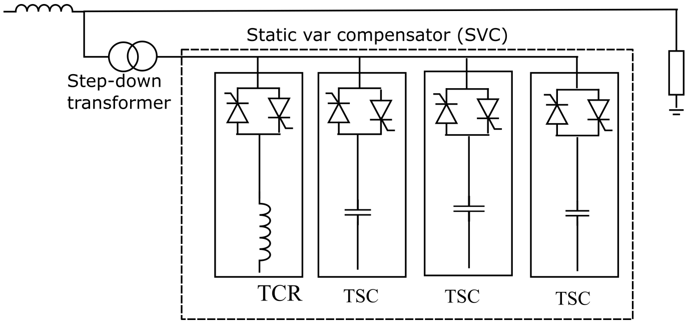

Fig. 1. SVC of the TCR-TSC Type [4].

III. METHODOLOGY

This section discusses the methods used to design the svc for improving the power supply of solar energy connected to the grid. In summary, it discusses the previous methods applied to the problem, the optimization and simulation tool and the mapping method to the problem.

A. Previous Methods

Uncertainty, there exist extreme reactive power injection by the system components or the customers' loads, the system's voltage increases while introducing excessive reactive power it goes low. However, the voltage's unreliability produced by the change in the required reactive power by the elements of the system and the customers' loads.

Several methods have been used to accomplish this such as system's structure reconfiguration, regulating generator excitation, synchronizing generator, variating the voltage by transformer's tap to regulate the power flow in the network, series compensation capacitor, switching in/out the shunt-reactor or shunt-capacitor are the traditional approaches used. Through these approaches the wanted objectives were not efficiently attained by attire and tear in the mechanical elements and slow response being the main glitches [5].

In 2019, [6] used SVC in a subsystem of 150KV to improve the voltage quality in West Java in Indonesia. As results, the implementation of SVC improved the voltage loss to 13.56 percent at Cibatu IBT 3-4 subsystem and the transmission line. In [7], authors discussed about Dragonfly algorithm and used this algorithm on IEEE 14 and 30 bus systems to study the size and cost of the SVC, voltage fluctuation and regulation of Static VAR during design process. A significant improvement of the voltage profile was noted using 100MVAR-SVCs.

However, it has been observed that voltage enhancement and power loss minimization are analyzed in unrealistic conditions (a one-time step) e.g. [8], [9].

Briefly, use of FACTS devices in dealing with power quality including voltage stability is well documented and new technology and algorithm are still under discussion [6], [7], [8], [9], [10], [11]. The majority of all existing methods suggested by cited in this study, optimize the allocation and settings of SVCs for dynamic voltage recovery or angular stability improvement.

B. Mapping Method to the Problem

Eberhart and Kennedy (1995) established Particle Swarm Optimization (PSO) as an optimization approach. It is mainly enthused from the behavior of the flock of bird and schooling of fish. In this manner, the system is initially attuned with a set of random answers and the optimization search is guaranteed by informing peers [12]. It is showed that the PSO provided improved answer quality and a lesser quantity of iterations compared to Genetic Algorithm (GA) technique. In comparison with GA, the PSO grants a shorter computational time and can be altered to actual cases for power networks. Few advantages and disadvantages of the PSO are presented below:

The advantages: To implement is simple; Need few constraints to regulate; have advanced possibility and efficacy in discovery the universal targets; Have short computational time.

The disadvantages: Can be hard to describe preliminary design parameters;Not operate out the problems of handful, etc. In a PSO system, the particles move in a complex search space. Each particle regulates its individual position and based on the knowledge of the nearest particle, utilizes the finest location came across by itself and its nearest, during flight [13].

IV. PROBLEM FORMULATION

In this section, the multi-objective function is expressed to find optimal location and size of SVC device by decreasing certain objective functions subject to sufficient network constraints.

Mathematical model of SVC: It is a shunt-connected static var generator or absorber whose output is attuned to argument capacitive or inductive current thus to keep and regulate exact parameters of the electrical power system (typically bus voltage). It is demonstrated as an ideal reactive power injection at the load ends [14]. The SVC current is expressed as follows

$$I_{\mathrm{SVC}} = jB_{\mathrm{SVC}}V_{\mathrm{k}} \tag{1}$$

The SVC reactive power, which is also the reactive power injected at bus k, is drawn:

$$Q_{\mathrm{SVC}} = Q_{\mathrm{k}} = -V_k^2 B_{\mathrm{SVC}} \tag{2}$$

Where $\mathrm{B}_{\mathrm{SVC}}$= the susceptance of SVC and V_{k} = the voltage at bus k.

Mathematical model of PSO: The swarm of individuals(particles) reset with a group (population) of arbitrary candidate solution change through the problem of d-dimension space to hunt the novel answers. The suitable position, pbest, is calculated. Respectively, each individual has its own location and speed. The suitable (best) location amongst the swarms, gbest, is updated in every iteration [14]. Their respective location and speed are updated following equations:

$$\begin{aligned} V_{\mathrm{k}}{}^{\mathrm{n+1}} = W_{\mathrm{k}}V_{\mathrm{k}}{}^{\mathrm{n}} + C_1 \times rand_1(pbest_{\mathrm{k}} \times S_{\mathrm{k}}{}^{\mathrm{n}}) + \\ C_2 \times rand_2 \times (gbest_{\mathrm{k}} - S_{\mathrm{k}}{}^{\mathrm{n}}) \end{aligned} \tag{3}$$

Where,

$$S_{\mathrm{k}}{}^{\mathrm{n+1}} = S_{\mathrm{k}}{}^{\mathrm{n}} + V_{\mathrm{k}}{}^{\mathrm{n+1}} \tag{4}$$

$$W = W_{max} - (\frac{W_{max} - W_{min}}{iterw_{max}}) \times iter \tag{5}$$

V_k^n= Velocity of k^{th} particle at n^{th} iteration; V_k^{n+1}= Velocity of k^{th} particle at $(n+1)^{th}$ iteration; S_k^n= Current location of particle k at nth iteration; S_k^{n+1}= Current location of particle k at $(n+1)^{th}$ iteration; $pbest_k$= individual suitable position of k^{th} particle; $gbest_k$ = Best global position of swarm (entire group of the particles); C_1= Coefficient of the self-recognition component; C_2 = Coefficient of the social component; $C_1 + C_2 = 4$ $rand_1$ and $rand_2$ are the random numbers usually chosen between [0, 1]; W= Inertia weight; W_{max}= Maximum value of inertia weight; W_{min}= Minimum value of inertia weight; $iter$ = Present iteration; $iterw_{max}$ = Maximum iteration.
The objective function is given:

$$minf = P_{\mathrm{Loss}} + \lambda VD \tag{6}$$

Where λ is the penalty co-efficient to give equal weightage for losses and VD is the voltage deviation.
The deviation of voltage at individually loaded bus have to be reduced as much as possible.

$$VD = \sum_{n=1}^{N_{PQ}} |V_m - V_{ref}| \tag{7}$$

So,

$$P_{\mathrm{Loss}} = \sum_{n=1}^{N_L} G_{\mathrm{mn}}(V_m^2 + V_n^2 - 2V_mV_ncos\delta_{mn}) \tag{8}$$

Where V_m= The voltage magnitude at bus m; V_n= The voltage magnitude at bus n; V_{ref}= The reference voltage; G_{mn}= The conductance of line m-n; δ_m= The voltage angle at bus i; N_L= The total number of transmission lines.

V. RESULTS AND DISCUSSION

This section demonstrates the improvement of power supply connected to the grid using static var compensator will focus on voltage and power quality. A fourteen-bus system is used to evaluate the efficiency of SVC. The efficiency of the proposed approach has been illustrated using the IEEE 14 bus test system shown in Figure 2. This network comprises six generators of which one is slack and there are 20 lines. The proposed practice has been verified on IEEE14-bus system,

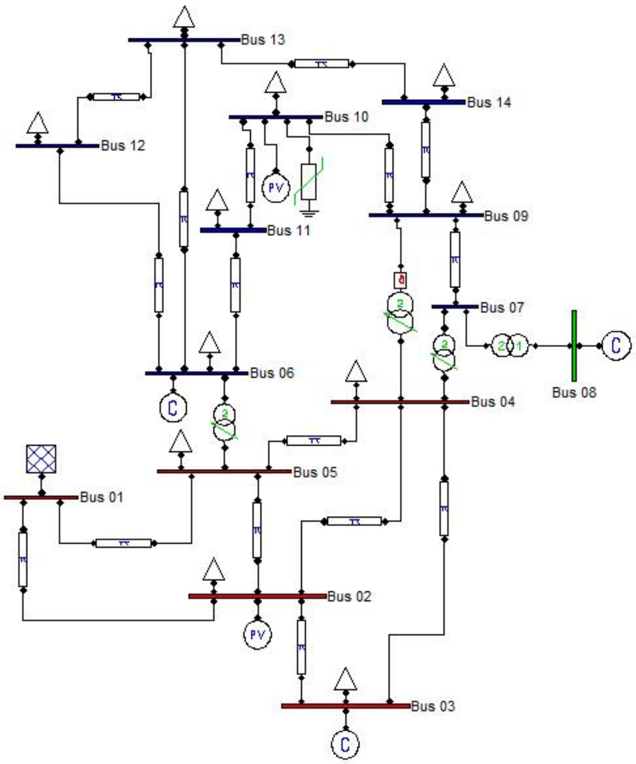

Fig. 2. IEEE 14 Bus system with SVC.

bus 2 and 10 are PV buses then 3, 6 and 8 are synchronous compensator buses and the load is modeled by PQ model.

The figure 3 illustrates the SVC result on voltage stability. It can be observed that the installation of the SVC increases the voltage stability compared to the base situation deprived of SVC. The figure proves that best location of SVC slightly attuned the voltages of PV buses and reducing the losses. The figure obviously shows that the buses voltages are in set of bounds at smallest active power loss with SVC at optimum position. A remarkable voltage improvement is only observed at bus no. 14 (Fig. 3, increase of 0.3 p.u) and power generation decreased by 10% p.u.

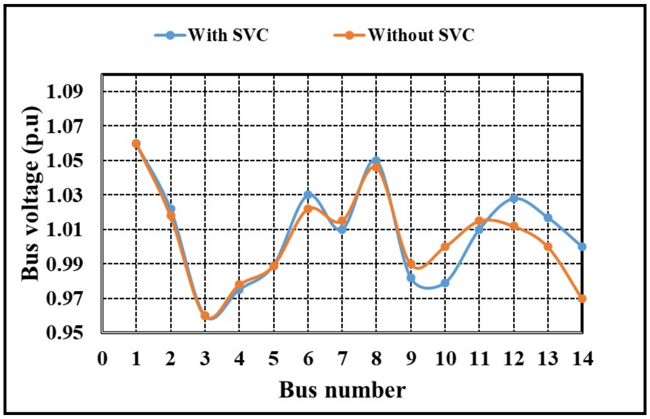

Fig. 3. Voltage profiles with and without SVC.

The active power flows in numerous positions are shown in Figure 4. The reduction in line losses is illustrated and the black line corresponds to the power flows with SVC and the red line represents the power flows without SVC. The losses are decreased once the SVC is optimally positioned.

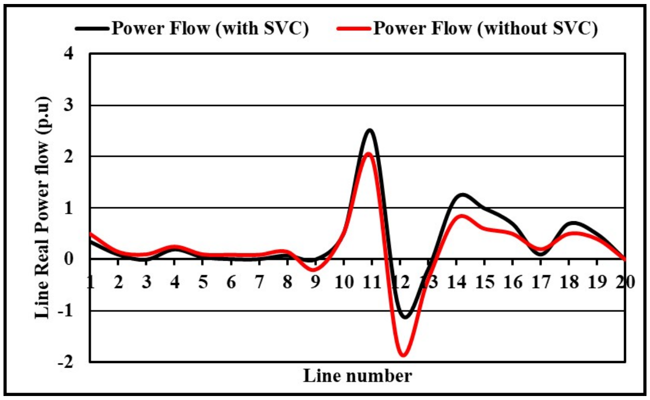

Fig. 4. Power flows with SVC and without SVC.

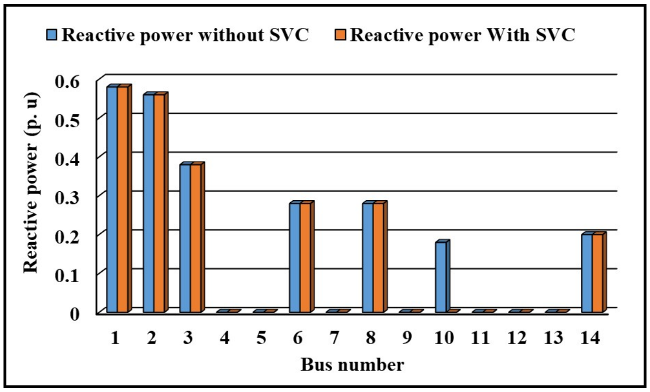

Fig. 5. Reactive Power Generation with and without SVC.

Figure 5 displays the bus generations at minimum reactive power loss with SVC at optimum place. The thick dark black bar signifies the generation at minimum reactive power loss by means of SVC and the white bars, the base state deprived of SVC.

CONCLUSION

In this work, SVC is used to improve the power system voltage stability. The absence of reactive power stretches positively to voltage instability, particularly once generators reach their bounds of reactive power production. Therefore, suitable compensation recovers and regulates voltage stability. The optimal introduction of SVC with particle swarm optimization technique presented a noticeable enhancement in the voltage stability with a comparatively small number of iterations and particles, therefore with a practical computational effort. The connection of the SVC in IEEE 14-bus providing well-enhanced voltage stability, the particle swarm optimization-based algorithm has been used to get the smallest voltage deviation and active power loss by optimally tracing of SVC device.

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