An optimal transmission line power control under non-sinusoidal conditions using static synchronous series compensator

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Abstract
In view of the growing load demand in developing countries, overloading in existing transmission lines is a major concern. In addition to the voltage drop due to overloading, the proliferation of non-linear loads in recent years distort the shape of sinusoidal voltage. Stable transmission of power through a transmission line under such condition is a challenge. In the presence of harmonics, control of transmittable power using static synchronous series compensator needs additional efforts, where increased power demand can be fulfilled by taking into consideration various other parameters. If an attempt is made to increase transmittable power through a transmission line using SSSC, power loss, the magnitude of voltage and its shape deteriorate in the presence of non-linear loads. Thus, the trade-off between transmittable power, transmission loss and voltage quality is tackled by optimal control of the compensator. In this study, a novel optimal control of SSSC is proposed with the objective of minimising transmission loss by maintaining the voltage within the limits while enhancing the transmittable power under non-sinusoidal conditions. A two-machine model of power system with 400 kV transmission line with parameters as per standards issued by the Central Electricity Authority is considered for validation of the algorithm using MATLAB platform and results are presented.

1 INTRODUCTION
With the growth in the economy, electrical load demand on existing transmission lines is increasing day by day worldwide. According to the Nepal Electricity Authority, the current peak load demand on Nepal grid is around 1500 MW, which is expected to increase by 2379 MW by 2022 [1]. The total peak load on Indian grid may reach to 239,609 MW by 2022 [2]. For stable and economic operation in such cases, it is necessary to enhance the transmission capability of the existing line up to its thermal capability without compromising system reliability and security. Transmittable power capacity of the existing transmission lines can be enhanced by utilising series compensation. Among all series compensation techniques, static synchronous series compensator (SSSC) is found to be the most advantageous series compensation device, as it provides an equal range of capacitive and inductive compensation and also is capable of exchanging reactive as well as real power with the power system [3, 4]. Power transfer through the line is increased by injecting a voltage in such a way that the angle between sending end and receiving end voltage is controlled as per load requirement. It also helps in maintaining the voltage at the desired value.

Many researchers have proposed and implemented control scheme for SSSC to control power flow through the transmission line effectively [5, 6]. Sen [5] proposed a simple control scheme using abc to dq transformation to control power flow through the transmission line using SSSC. However, the time response was not included in the study. Rig et al. [6] improved the time response by including one additional inner power loop, and similar time response for higher as well as lower value of transmitted power is achieved. In both the above studies, SSSC is implemented in constant reactance mode, where the inserted series voltage depends upon line current. In this mode, SSSC exhibits similar characteristics as conventional series compensation schemes; however, the issue of sub-synchronous resonance (SSR) may arise. It is found that SSSC has a substantial capability of excluding the problem of SSR if operated in constant voltage mode. In constant voltage mode, SSSC provides the inherent functional characteristic of offering an independent controllable compensating voltage. To analyse the effect
of both the modes of operation, El Moursi et al. [7] proposed an optimal control scheme for implementing SSSC in both the modes, and it is proved that performance in constant reactance mode is better for voltage regulation and damping oscillations. The beauty of constant voltage mode is that the compensating series voltage can be inserted independent of line current. Few more studies reported optimal control of flexible alternating current transmission system devices [8–10] to control the power flow through the transmission line, where SSSC is implemented in constant voltage mode. Optimal utilisation with sizing is reported in [8], total deviation from the prescribed control targets is minimised in [9], and transmission line losses are minimised in [10] for controlling the power flow through the transmission line.

Recently, field performance of SSSC is analysed by Yue et al. [11], where research has been made on power flow regulation capability of SSSC to the power grid by considering SSSC that is built in Tianjin 220 kV line in June 2018 as an example. Nowadays, distributed generations are growing quickly, so to improve controllability and flexibility in power transmission in distributed power systems, SSSC is proposed and implemented [12,13]. In all the above techniques, sinusoidal current and voltage are assumed; however, such sinusoidal conditions are rarely seen in today’s power system.

With the development of power electronics, power quality (PQ) becomes an important issue because of the proliferation of non-linear loads. Non-sinusoidal voltage drop appears across the transmission line impedance because of this distorted current drawn by such loads [14]. So the voltage may become non-sinusoidal at different points of the power system. Also, such non-sinusoidal voltage and current cause overheating and increase transmission losses. Implementation of SSSC under non-sinusoidal conditions has become a challenge in the current scenario. According to the standards and regulations provided by Central Electricity Authority (CEA), voltage waveform quality should be maintained at all the points on the transmission line, and voltage total harmonic distortion (THD) should be limited to 5% in addition to the ± 5% variation in magnitude [15]. Enhancement of power transfer capacity under non-sinusoidal conditions is not addressed in many of the available literature. A novel optimisation scheme for implementing SSSC under non-sinusoidal conditions is proposed in this study, where transmittable power for tie line is enhanced with improvement in PQ. Also, minimisation of transmission loss is taken as the objective function as it is one of the important concerns in the power system.

This study is organised as follows: Section 2 presents the power loss derivation in the tie line under non-sinusoidal condition; Section 3 deals with the proposed optimisation technique; Section 4 discusses the results obtained; and in Section 5, the conclusion is presented.

2 | POWER LOSS IN THE TIE-LINE UNDER NON-SINUSOIDAL CONDITIONS

A two-machine model of a power system is considered here for analysis. Although the two-machine model is a special case, the performance provides a physical understanding, which is helpful in dealing with more complex cases. Figure 1 shows the single-line diagram of the two-machine model of power system connected by a tie line having resistance $R$ and reactance $X_L$ at the fundamental frequency.

$$V_i, V_k, V_L, V_L'$$ and $I_L$ in the diagram are the rms values of sending end voltage, midpoint voltage, receiving end voltage, transmission line voltage drop and line current, respectively. $\delta_i, \delta_k$ and $\delta_j$ are phase angle at the respective points.

Under linear load conditions, the power flow equations in presence of SSSC are presented in [16] and loss equation in such transmission line is derived. When the non-linear load is connected in the power system, harmonic current causes non-sinusoidal drops along the transmission line, and midpoint voltage may get distorted to the maximum in the line. Also, the active and reactive powers through the transmission line are decided by similar order harmonics of voltage and current and phase angle between them [17]. The cross product of unlike frequency components will contribute to distortion power. The total apparent power ‘$S_{ik}$’ includes distortion power ‘$D_{ik}$’ along with real power ‘$P_{ik}$’ and reactive power ‘$Q_{ik}$’. Because of harmonic components, current drawn from the supply increases to meet the increased distortion reactive power demand. So transmission line losses will increase. The transmission loss under the non-sinusoidal condition without and with SSSC is derived below.

### 2.1 | Transmission loss equation under non-sinusoidal conditions without SSSC

Under the non-sinusoidal situation, by assuming both voltage and current non-sinusoidal, apparent power flow equation from ‘$i$’ bus to ‘$k$’ bus is given by

$$S_{ik} = \sqrt{P_{ik}^2 + Q_{ik}^2 + D_{ik}^2} = V_i' I_L'$$  \hspace{1cm} (1)

where

$$V_i = \sqrt{V_{i1}^2 + V_{i2}^2 + V_{i3}^2 + \cdots + V_{in}^2}$$  \hspace{1cm} (2)

$$I_L = \sqrt{I_{L1}^2 + I_{L2}^2 + I_{L3}^2 + \cdots + I_{Ln}^2}$$  \hspace{1cm} (3)

where 1, 2, 3, ..., $n$ are the order of harmonics. In general, $I_{L_n}$ in terms of the midpoint voltage $V_{k3}$ and corresponding...
admittance \( Y_{ikn} \) are given as

\[
I_{ikn} = (V_i - V_{kn}) \ast Y_{ikn}
\]

Substituting \( V_i \) and \( I_{ikn} \) in Equation (1), \( S_{ik} \) is given as

\[
S_{ik} = \left\{ \sum_{n=1}^{N} \left[ V_i^2 (\cos 2\delta_{kn} + j\sin 2\delta_{kn}) \right] \right\} \times \sum_{n=1}^{N} \left[ (V_i (\cos \delta_{kn} + j\sin \delta_{kn}) - V_{kn} (\cos \delta_{kn} + j\sin \delta_{kn})) Y_{ikn}^* \right] Y_{ikn} \]

(5)

Similarly, apparent power flow \( (S_{ik}) \) from \( k' \) bus to \( i \) bus can be written. Transmission line loss \( 'P_{ikn}' \) is given by

\[
P_{ikn} = \text{Real} (S_{ik}) - \text{Real} (S_{ik})
\]

(6)

Total loss \( 'P_{ik}' \) in the line will be double of \( 'P_{ikn}' \).

2.2 Transmission loss equation under non-sinusoidal conditions with SSSC

Assuming SSSC is connected at the midpoint of the line, a single-line diagram of the two-machine model with SSSC embedded is shown in Figure 2.

SSSC is meant basically for the control of power transfer through the transmission line by injecting voltage in series with the transmission line at a predefined phase angle with line current. Power flow equation in presence of SSSC \( 'P_{ik}' \) from \( i \) bus to \( k' \) bus with non-linear load is given by

\[
S_{ik} = \left\{ \sum_{n=1}^{N} \left[ V_i^2 (\cos 2\delta_{kn} + j\sin 2\delta_{kn}) \right] \right\} \times \sum_{n=1}^{N} \left[ (V_i (\cos \delta_{kn} + j\sin \delta_{kn}) - V_{kn} (\cos \delta_{kn} + j\sin \delta_{kn})) Y_{ikn}^* \right] Y_{ikn} \]

\[
+ j\sin \delta_{kn} + V_{kn} (\cos \delta_{kn} + j\sin \delta_{kn})) Y_{ikn}^* \right] Y_{ikn} \right\} \frac{1}{2}
\]

(7)

The above equation shows that power flow through the line can be controlled by controlling injected voltage \( 'V_{ikn}' \). It is also understood that power loss varies with \( 'V_{ik}' \). Also, if an attempt is made to enhance the transmission line power under non-linear load condition, power loss and voltage quality in terms of magnitude, as well as the shape, will deteriorate. Thus, there is a need for optimisation for efficient implementation of SSSC.

Hence, a novel optimal control of SSSC is proposed in the next section.

3 Proposed Optimisation Technique

The proposed optimal control scheme enhances the power transfer through the transmission line with the objective of minimising the transmission loss by considering voltage quality under non-sinusoidal conditions. Also, the desired power flow is met by enforcing power balance equation as equality constraint. This is achieved by properly injecting a voltage in series with the transmission line using SSSC.

The above problem is non-linear in nature, as both objective function and constraints are non-linear. Hence, the optimisation technique used here is ‘sequential quadratic programming’ (SQP). SQP is being used since long and has a rich history in solving the non-linear constraint optimisation problem. For SQP, Lagrange function is to be formed with Lagrange multipliers. Then, the function can be solved by necessary conditions known as Kuhn–Tucker conditions. Here, Hessian of the Lagrangian function is used for solving optimisation problem [18].

3.1 Objective function

Minimisation of transmission line losses is taken as the objective function. The objective function \( 'F' \) in terms of control variables is given as

\[
F = \text{Min} \left[ \sum_{i=1}^{N} \left( V_{k1} + \delta_{k1}, V_{i1}, \delta_{i1}, \ldots, V_{kn}, \delta_{kn} \right) \right]
\]

(9)

All the variables are bounded through lower and upper limits. As the fundamental magnitude of the voltage at midpoint \( V_{k1} \) is taken as one of the variables, so its magnitude is controlled by imposing lower and upper limit as

\[
0.95V_{ph} \leq V_{k1} \leq 1.05V_{ph}
\]

\( 'V_{ph}' \) is the magnitude of phase voltage at the sending end.
3.2 Equality constraint

Power balance equation is taken as equality constraint \(U\), which is given as

\[
U = P_G - P_{L_{ik}} - P_D = 0
\]

(10)

where the generated power \(P_G = \text{Real}(S'_{ik})\) and \(P_D\) is load demand on the transmission line. Substituting expressions for \(P_G\) and \(P_{L_{ik}}\) from Equations (7) and (8), respectively, in Equation (10), equality constraint \(U\) is obtained as

\[
U = \text{Real}(S'_{ik}) - P_D
\]

that is,

\[
U \left[ \sum_{n=1}^{n} \left[ V_{k_2}^2 (\cos 2\delta_{k_2} + j \sin 2\delta_{k_2}) \right] \right] \times \left[ \sum_{n=1}^{n} \left[ V_{i_2} (\cos \delta_{i_2} + j \sin \delta_{i_2}) - V_{i_1} (\cos (\delta_{i_1} + j \sin (-\delta_{i_1})) - V_{i_1} (\cos \delta_{i_1} + j \sin \delta_{i_1}) \right] Y_{k_2} \right]^{1/2} - P_D
\]

(11)

3.3 Inequality constraint for voltage THD

THD in voltage at the midpoint is taken as inequality constraint \(W\). Let the THD limit in voltage be \(V_{THD}\). Then, the inequality constraint is taken as

\[
\sqrt{\left( \sum_{n=1}^{n} V_{k_2}^2 / V_{k_1} \right)} \leq V_{THD}
\]

(12)

\(V_{k_2}\) is given as

\[
V_{k_2} = \left( V_{i_2} (\cos \delta_{i_2} + j \sin \delta_{i_2}) - \left( \frac{1}{n} \right) (V_{i_1} (\cos \delta_{i_1} + \sin \delta_{i_1}) - V_{i_1} (\cos (\delta_{i_1} + j \sin (-\delta_{i_1})) - V_{i_1} (\cos \delta_{i_1} + j \sin \delta_{i_1}) \right) / (Y_{k_2}) \right)
\]

(13)

So inequality constraint \(W\) is taken as

\[
W = \left( \sqrt{\left( \sum_{n=1}^{n} V_{k_2}^2 / V_{k_1} \right)} \right) - V_{THD} \leq 0
\]

(14)

3.4 Lagrange function

Lagrange function \((L)\) can be written as

\[
L = P'_{L_{ik}} + \lambda (U) + \mu (W)
\]

(15)

\[
L = P'_{L_{ik}} + \lambda (\text{Real}(S'_{ik})) - P'_{L_{ik}} - P_D
\]

(16)

By solving the above equations, optimised values for \(V_{\mu}\) and their phases \(\delta_{\mu}\) can be obtained by satisfying all the constraints. Flow chart for the used algorithm is presented in the flow chart shown in Figure 3.

Midpoint voltage \(V_{k_2}'\) and line current \(I_{L_{ik}}\) are sensed, and optimised value of reference compensating voltage \(V_{s_{ref}}\), to be injected by the inverter across the secondary of the series transformer of SSSC, is obtained by implementing the proposed algorithm. A sinusoidal pulse width modulation is implemented.
and switching pulses for the inverter are obtained. According to the switching pulses, compensating series voltage ‘\( V_s \)’ is generated and inserted into the system through a series coupling transformer.

4 | SIMULATION RESULTS

A MATLAB simulation is carried out using the two-machine model of the power system by installing SSSC at the midpoint of the transmission line. MATLAB model is shown in Figure 4. Power is assumed to be transferred from machines I and II. A 400 kV, 400 km long transmission line is selected for analysis.

The most common type of conductor used is aluminium conductor steel reinforced (ACSR) for extra high voltage transmission lines. The resistance and inductance of the line are 0.02880 and 0.307 \( \Omega \) per km, respectively [15]. As per the standard provided by CEA, the thermal capacity of the ACSR Moose conductor for 75°C operating temperature can be uprated to 1702 MVA [19, 20]. Maximum power carrying capacity of the selected 400 kV, 400 km long transmission line is 1170 MW [3].

Following stages are considered for analysing proposed optimal control of SSSC:

Stage I: Performance analysis without SSSC
Stage II: Performance analysis using the proposed optimal control of SSSC

Stage I: Performance analysis without SSSC
Various parameters of the two-machine model under linear and non-linear load conditions without SSSC are analysed here.

### TABLE 1 | Parameters under linear load without static synchronous series compensator (SSSC)

| Linear Load (MW) | Load angle (°) | \( V_k \) (kV) | \( I_L \) (Amp) | \( P_L \) (MW) |
|------------------|---------------|---------------|----------------|-------------|
| 500              | 23            | 226.1         | 750            | 18          |
| 750              | 36.6          | 219.1         | 1180           | 48.1        |

(i) Performance under linear load

To compare the performance of SSSC under various conditions, first, simulation is carried out with the linear load. For long transmission lines, power transfer capability is decided by stability factors. So by taking the typical value of load angle 30 degrees, power transfer will be limited to around 630 MW. To understand the necessity of SSSC, two load conditions are considered, one below 630 MW and the other above 630 MW load. To achieve this, the load is increased from 500 to 750 MW at 0.1 s. Observations are presented in Table 1. For the 400 kV transmission line, per phase voltage limit for ‘\( V_k \)’ is 219.4 to 242.4 kV.

It can be observed from Table 1 that with increased load demand, transmission line loss has increased to 48.1 MW with a further drop in midpoint phase voltage to 219.1 kV and increase in load angle from 23 to 36.6 degrees. Also, the magnitude of \( V_k \) and load angle, both has crossed the limiting criteria though power transmitted is increased to 750 MW. Hence, compensation is needed to transmit 750 MW power safely. As load is linear in nature, the current waveform will remain sinusoidal and the system will remain harmonic-free. Figure 5 represents the waveforms for voltage at midpoint ‘\( V_k \)’ and line current ‘\( I_L \)’ in
FIGURE 5 Waveforms for (a) midpoint voltage, (b) line current when the load is increased from 500 to 750 MW

TABLE 2 Parameters under non-linear load without SSSC

| Load (MW) | Load angle (°) | $V_k$ (kV) | THD $V_k$ (%) | $I_L$ (Amp) | THD $I_L$ (%) | $P_L$ (MW) |
|-----------|----------------|------------|---------------|-------------|---------------|------------|
| 750       | 36.8           | 218.9      | 11.4          | 1183        | 6.4           | 48.4       |

TABLE 3 Voltage harmonics at the midpoint for 750 MW load

| Sl. no | Harmonic order | $V_k$ (kV) | Phase of $V_k$ (°) | Sequence |
|--------|----------------|------------|---------------------|----------|
| 1      | 1st            | 217.50     | -18.4               | Positive |
| 2      | 5th            | 20.90      | -76.4               | Negative |
| 3      | 7th            | 10.49      | -130.2              | Positive |
| 4      | 11th           | 5.05       | -67.4               | Negative |
| 5      | 13th           | 3.463      | -108.0              | Positive |

For analysing a general practical case, a combination of the linear and non-linear loads is connected to the power system in this case. The load is switched from 500 MW linear to 750 MW non-linear at 0.1 s. To achieve this, in addition to a linear load of 500 MW, a six-pulse diode converter with current THD of around 30% with a rating of 250 MW as the non-linear load is connected in the system at 0.1 s. Magnitude of $V_k$, THD of $V_k$, $I_L$, THD of $I_L$ and transmission loss is presented in Table 2.

It is found that the transmission losses are increased by 0.62% as compared to the linear load of the same rating as mentioned in Table 1. It is seen that load angle also further got deteriorated in presence of non-linear load to 36.8 degrees. Harmonic component of 1st, 5th, 7th, 11th and 13th components of voltage at midpoint $V_k$ with their phases and sequence is presented in Table 3.

Waveforms for voltage at midpoint $V_k$ and line current $I_L$, in this case, is given in Figure 6. It is clearly seen from Figure 6 that the voltage at midpoint $V_k$ and line current $I_L$ get distorted after connecting the non-linear load to the system at 0.1 s.

Stage II: Performance analysis using the proposed optimal control of SSSC

Performance analysis of the two-machine model under linear and non-linear load conditions with SSSC at the midpoint is analysed here.
TABLE 4  Measured parameters under linear load with SSSC

| Load (MW) | Load angle (°) | \( V_k \) (kV) | \( I_L \) (Amp) | \( V_{se} \) (kV) | \( P_{loss} \) (MW) |
|-----------|----------------|----------------|----------------|----------------|----------------|
| 750       | 30.0           | 222.4          | 1165           | 25             | 46.7           |
| (without applying optimal control scheme) |
| 750       | 17.6           | 225.3          | 1107           | 70             | 41.4           |
| (by applying optimal control scheme) |

(i) Performance under linear load with SSSC

The proposed optimal scheme is implemented using SSSC for increased load demand of 750 MW of power, which is linear in nature, as mentioned in stage I. Results are produced in Table 4. The results obtained using SSSC without optimal control are also presented in Table 4 for understanding the effectiveness of optimal control of SSSC. It is found that with optimal control, the load angle and transmission loss can be reduced while maintaining the voltage within the limit for the same power transfer.

Comparing power control with and without SSSC, the power of 750 MW could be transferred safely through the transmission line while transmission losses are reduced to 41.4 from 48.1 MW and load angle is reduced from 36.6 to 17.6 degrees. Also, voltage \( V_k \) also improved to 225.4 from 219.1 kV, which was exceeding its limit. Waveforms for voltage at midpoint \( V_k \) and transmission line current \( I_L \) at 750 MW load are projected in Figure 7.

It can be seen from the waveforms in Figure 7 that after inserting the optimised SSSC at 0.1 s, the magnitude of \( V_k \) has improved, while magnitude of line current has dropped for the same power through the transmission line.

(ii) Performance under non-linear load with SSSC

Simulation is performed with a combination of the linear and non-linear loads of 750 MW. Per phase waveform for reference compensating voltage \( V_{sef} \) obtained by applying the proposed optimisation algorithm for 5% THD is shown in Figure 8.

It is observed that losses are reduced to 42.6 from 48.4 MW for 5% THD limit at the midpoint. Waveforms for voltage at midpoint before and after compensation and generated compensating wave \( V_{se} \) in phase ‘\( a \)’ are given in Figure 9, and it is found that THD of \( V_k \) is improved from 11.43 to 5%.

It is seen that the quality of load current also enhanced with improvement in voltage THD at the midpoint. Waveforms for line current before and after compensation are presented in Figure 10. It is observed that THD in line current is improved from 6.4% to 2.5% after compensation.

It is found that with the proposed method, increased load demand of 750 MW, which is non-linear in nature, is transferred effectively with minimum transmission loss while maintaining load angle, voltage magnitude and harmonics within the limit.
Various parameters measured for increased load demand of 750 MW without SSSC and with proposed optimal control of SSSC are shown in Table 5 for comparison.

From Table 5, it is clear that the proposed algorithm is capable of transferring the desired power with minimum loss while meeting the statutory norms for voltage magnitude and THD with improved stability.

To show the effectiveness of the proposed algorithm in the enhancement of power transfer under non-sinusoidal condition, simulation is performed at load angle 30 degrees and observations are produced in Table 6.

It is clearly indicated from Table 6 that by using proposed optimal control of SSSC, a non-linear load of 960 MW can be transmitted safely by maintaining voltage magnitude and THD

### Table 5

| Parameter            | Without SSSC | With proposed optimal control of SSSC |
|----------------------|--------------|---------------------------------------|
|                      | Linear       | Non-linear                            | Linear       | Non-linear |
| THD in $V_k$ (%)     | 0            | 11.43                                 | 0            | 5          |
| $P_k$ (MW)           | 48.1         | 48.4                                  | 41.4         | 42.6       |
| $V_k$ (kV)           | 219.1        | 218.9                                 | 225.3        | 223.0      |
| Load angle (deg.)    | 38.6         | 38.8                                  | 17.6         | 17.5       |

### Table 6

| Case               | Power transfer (MW) | $P_k$ (MW) | $V_k$ (kV) | THD in $V_k$ (%) |
|--------------------|---------------------|------------|------------|------------------|
| Without SSSC       | 630 (non-linear)    | 36.4       | 221.9      | 25.1%            |
| With SSSC          | 960 (non-linear)    | 90.0       | 222.9      | 5%               |
**FIGURE 9** Waveforms of $V_k$ (a) before compensation, (b) after compensation, (c) generated compensating voltage $V_{se}$.

**FIGURE 10** Waveforms of $I_L$ (a) before compensation, (b) after compensation.
within the limit instead of 630 MW non-linear load without SSSC.

5 | CONCLUSION

This study presents a novel optimal control algorithm for the implementation of SSSC under non-sinusoidal conditions with an objective of minimizing the transmission line loss while enhancing the transmittable power. It does this by considering the magnitude and distortion in voltage at the midpoint of the transmission line. The algorithm is verified in a two-machine model of the power system with SSSC at the midpoint of the transmission line. The specialty of the proposed algorithm is that it works well with linear and non-linear conditions. Also, it is possible to set THD limit per the requirement so that the rating of the SSSC can be reduced. It is also indicated that the transmittable power through transmission line can be controlled and enhanced approximately by 50% for stable operation by SSSC in presence of the non-linear load by maintaining voltage THD in a limit. Validation is done satisfactorily by using MATLAB digital platform.

It is found that the algorithm can be easily modified for active power control of SSSC by taking $X/R$ ratio as one of the constraints. A future work is being carried out to address $X/R$ ratio that further reduces transmission loss with improved power system stability and power oscillations damping. In linear conditions, it is analysed and proved that power oscillations damping gets improved with SSSC.

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