Power System Performance Enhancement through Compensation Techniques

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Abstract

Demands for electricity had increased tremendously over the years and subsequently power systems need to be augmented in size and performance. One possible way of enhancing the performance of power systems is through transmission lines performance upgrading. Series compensation technique is found to be very effective in heightening the power transmission line's loadability; hence it is practiced widely due to its cost effectiveness. In this research paper, a percentage compensation software package has been developed to illustrate the benefits of series compensation. This package consists of various compensation configurations such as: single capacitor configuration, twin capacitors-optimum configuration, twin capacitors-optional capacitors configuration and twin capacitors-optional placement configurations. The MATLAB GUI platform is used for the development of the software package.

Keywords: Performance Enhancement, Power Systems, Series Compensation, Software Package

1. Introduction

Due to the growth in population, industrialization and the change in living culture, the demand for electricity has become higher and it is going to continue in the future too. Though there is a huge demand for electricity, the power generating facilities available now are insufficient. Hence there is a need for adding new electric power stations that involves a mammoth amount of investments and time for enactment[1-3]. Even if the power generating sources are newly added, the generated power has to be delivered to the customers through transmission and distribution networks, which also needs a colossal investment. Investments on both new generating facilities and power transmission systems at the same time will be a burden for electric utilities. In order to avoid huge investments on two tasks together, an option could be, improving the operating performance of the existing facilities in stages[4-6]. Therefore, this paper addresses a cost effective way of improving the performance of the existing power transmission systems by applying compensation techniques.

Though there are several ways of improving the performance of transmission systems by compensation techniques, they are generally classified as series compensation, shunt compensation and series-shunt compensation together[7-12]. Some of these techniques are[13-18]

- Flexible AC Transmission Systems (FACTS) Controllers
- Static Var Compensators (SVC), and
- Static Synchronous Compensators (STATCOM)

Apart from these, Mechanically Switched Capacitors for series compensation of power transmission lines are gaining popularity in the modern world[10].

The proposed research work aims at series compensation of transmission lines since it is a proven and time-honored technology in terms of reducing the "effective line impedance," thereby improving the power transfer capability of transmission lines[3,4,9,10]. The theoretical concept is well-known through research and massive publications; hence no elaborate discussions are needed. Instead, the applications of the knowledge through a software package developed exclusively by the authors are discussed here.

2. Series Compensation Configurations

Series capacitors may be installed at one or both ends of a transmission line. Line ends are archetypal capacitor locations, because it is commonly possible to use the space available in sub-stations. Consequently, this reduces installation/capital cost. Alternatively series capacitors shall be installed at some central location on the line. Series capacitors placed at the line ends generate added complex protection problems than those installed at the center of the line. Moreover, capacitors could be mounted at strategic locations with their optimum values at economical values.

The various compensation configurations proposed are:
- Single capacitor configuration,
- Twin capacitor-optimum configuration,
- Twin capacitors-optional capacitors configuration, and
- Twin capacitors-optional placement configuration.

All these configurations are centered on the basic compensation principle and the analytics are available in the literatures[4,10].

3. Software Package Development

A Windows based software package has been developed by the authors to ease the application of series compensation to achieve maximum power transfer. The developed package is simple in operation but efficient in application. The MATLAB GUI platform is used for the development of the software package. To support its portability, the package is developed as a stand-alone package.

Figure 1. presents the interactive software developed with the various compensation techniques as discussed in section 2. It has the openings for entering the transmission line data (Inputs) such as:

3.1 Inputs
- Resistance per unit length,
- Reactance per unit length,
- Susceptance per unit length,
- Sending end voltage,
- Receiving end voltage,
- Line operating angle, and
- Degree of compensation.

3.2 Compensation Options
Four options are available to select the compensation configurations such as:
- Single capacitor configuration,
- Twin capacitors-optimum configuration,
- Twin capacitors-optional capacitors configuration, and
- Twin capacitors-optional placement configurations.

3.3 Compensation options
The outputs such as:
- Series capacitor reactance (Ohms),
- Maximum power transfer (MW),
- Power transfer efficiency (%),
- Maximum power generated at the sending end, and
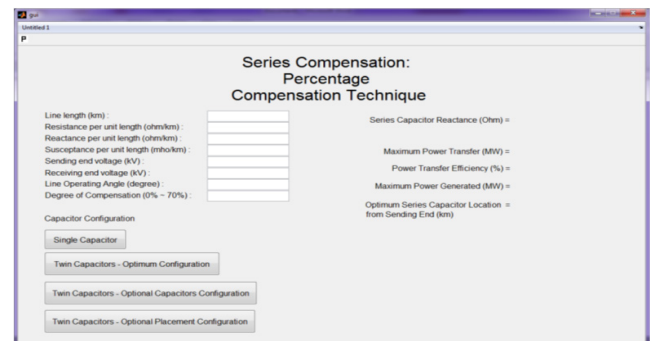- Optimum capacitor locations from sending end (km) will be displayed.

Figure 1. Working main window.

A sample power transmission system has been considered to demonstrate the suitability of the software package developed and the results are compared for the various options of series capacitor configurations.

4. Results and Discussions

4.1 Single Capacitor Configuration
Among the four configurations, the single capacitor option (Option 1) is chosen first. Considering primarily the thermal rating of the transmission line, line parameters such as conductor diameter and clearance between conductors, transmission efficiency and system stability, the degree of compensation is physically limited to a maximum value of 70 percent[19].

As observed from Figure 2, with 25% degree of compensation, the power transmission line has a

maximum power transfer capability of 726.033 MW with a power transfer efficiency of 93.54%. The corresponding series capacitor reactance value and its placement location are 28 Ω and 188 km away from the sending end respectively. The maximum power transfer of a power transmission system is improved by 173.76 MW compared to an uncompensated transmission system. It is worth noticing that the location of the series capacitor is not at the centre and shifted towards the receiving end.
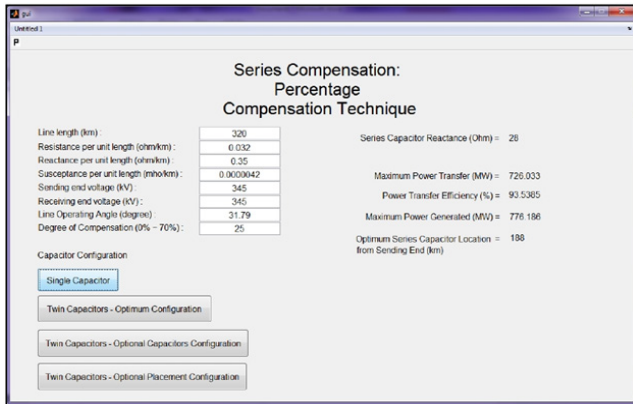

Figure 2. Single capacitor.

4.2 Twin Capacitor-optimum Configuration

Twin Capacitor-optimum Configuration is chosen next (Option 2). In twin series capacitor configuration, each series capacitor is connected at a distance away from the sending end and receiving end respectively. In this option, all possibilities of series capacitors locations with various capacitive reactance values of the two capacitors are examined to maximise the power transfer of a power transmission system. Though it is a laborious and time consuming job, the software presents the optimum results in a much shorter time.
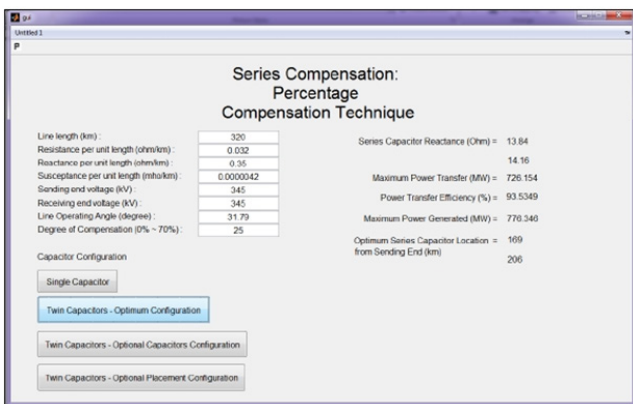

Figure 3. Twin capacitors-optimum configuration.

As observed from Figure 3, with 25% degree of compensation, the power transmission line has a maximum power transfer capability of 726.154 MW with a power transfer efficiency of 93.54%. The two series capacitor reactance values are found to be 13.84 Ω and 14.16 Ω, and their respective locations are 169 km and 206 km away from the sending end. However, the total value of both capacitors remains the same as 28 Ω as in the case of single capacitor configuration. The maximum power transfer of a power transmission system is improved by 173.76 MW (as in the case of single capacitor) compared to an uncompensated transmission system. There is no change in the power transfer and the transfer efficiency with respect to single capacitor option. The advantage is the reliability of compensation is improved due to twin capacitors; even if one capacitor fails due to technical and manufacturing defects, the other will function and provide some level of compensation. Limitation of this approach are (i) the optimum capacitors values should be available in the market, and (ii) to place the capacitors, proper locations (sub-stations) should be available at the optimum locations arrived at.

4.3 Twin Capacitor-optional Capacitor Values Configuration

Twin Capacitor-optional Capacitors Configuration is chosen next (Option 3). From the twin series capacitors percentage compensation method's outcome, two optimum values of capacitors are obtained, which may not be available in the market. Under such circumstances, electric utilities shall decide the use of capacitors readily available in the market. With such defined capacitors values, maximum power transfer at the optimum locations shall be obtained from this option. When the Twin Capacitor-Optional Capacitors Configuration option is chosen from the Main Window, a new window appears to enter the utility's defined values and the results are displayed there itself as in Figure 4.

For the optional capacitors values of 12 Ω and 16 Ω (still the total value remains as 28 Ω – to compare the performances of the various options under the same condition), the power transmission line has a maximum power transfer capability of 726.152 MW with a power transfer efficiency of 93.54%. The two series capacitors locations are found to be 167 km and 204 km from the sending end respectively. The increase in power transfer is around 173.76 MW. It is noticeable that the maximum

power transfer and the optimum locations are slightly different from the earlier options.
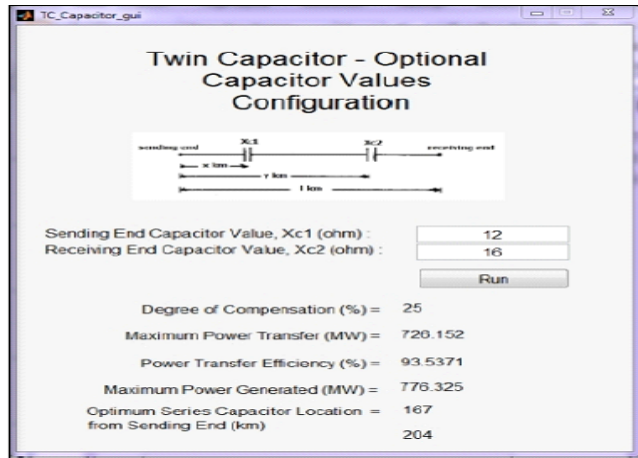

Figure 4. Twin capacitors-optional capacitor values.

4.4 Twin Capacitor-optional Capacitors Location Configuration

The fourth option is Twin Capacitor-optional Capacitors Locations (Placement) Configuration. The utilities define the locations. Once the new locations are entered in this option 4, the results are displayed as in Figure 5. and the Figure 5. is self-explanatory.

4.5 Comprehensive Results

Since the power transfer is a function of the capacitive reactance of the series capacitor and the location of the series capacitor placement, the problem of determining the capacitive reactance and the optimum location for achieving maximum power transfer are generally solved separately. However, the software package developed performs both tasks together, and provides the optimum values instantly. The earlier parts (sections 4.1 to 4.4) demonstrated all the four options for a fixed degree of compensation (say 25%) only. In reality, the compensation degrees are variable depending upon transmission system's physical and operational constraints. Hence, Table 1 provides the consolidated results of the various capacitor configurations with variable degrees of compensations.
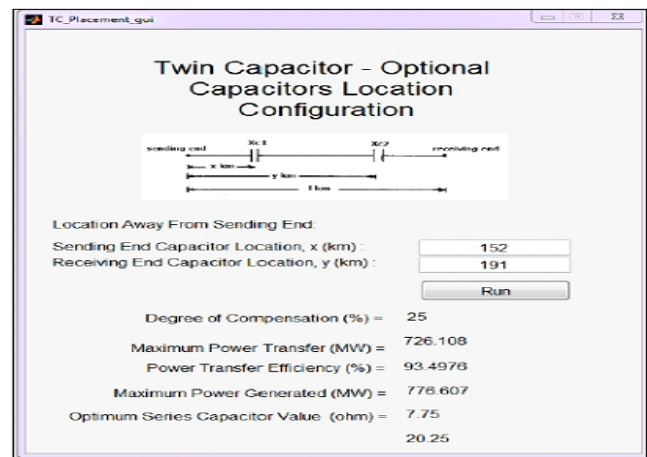

Figure 5. Twin Capacitors-Optional Capacitor Locations.

Table 1. Comprehensive results

Degree of Compen-sation	Maximum Power Transfer (MW)		Series capacitor location away from sending end (km)		Series capacitor value (Ω)		Increase in Power Transfer (MW)	
	Single Capacitor	Twin Capacitor	Single Capacitor	Twin Capacitor	Single Capacitor	Twin Capacitor	Single Capacitor	Twin Capacitor
0	554.962		0		0		0	
10	612.581	612.857	187	180	11.2	5.65	57.619	57.895
				195		5.55		
20	684.003	684.059	188	173	22.4	11.31	129.041	129.097
				203		11.09		
30	773.445	773.683	188	166	33.6	16.74	218.483	218.721
				210		16.86		
40	888.998	889.734	189	159	44.8	22.28	334.772	334.772
				218		22.52		
50	1043.370	1045.31	190	153	56	27.88	488.408	490.348
				226		28.12		
60	1258.050	1262.78	191	148	67.2	33.57	703.088	707.818
				235		33.63		
70	1569.55	1580.380	195	146	78.4	39.28	1014.588	1025.418
				245		39.12		

5. Conclusion

The presented paper addressed the power transmission line performance upgrading through the cost-effective series compensation technique. Both single and twin capacitor configurations were adapted to achieve the desired target. A user-friendly software package has been developed on MATLAB GUI platform with four options. Each option has its own special characteristics, and screen shots are provided wherever possible for the better understanding of learners and practicing power engineers. Though the package addresses practicable operations suitable for real-time applications, still few options such as cost-effectiveness, security and stability need to be addressed in the near future.

6. References

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