Comparative investigation of DG and DSTATCOM utilizing the PLI technique in a 33-bus radial distribution system for loss reduction

Abstract:

This study offers a novel strategy that combines DG with DFACTS in support of the reactive component in order to reduce the loss related to the loss of the active component. The use of distributed generation (DG) and distributed FACTS (DFACTS) improves the Loss of voltage and power in the distribution radial line networks. The best location and size for the compensating devices have been determined using the PLI method. The experiment, which uses the widely used in distribution radial line scheme for IEEE 33-bus, shows the effectiveness of the suggested tactic.

Keywords: Distributed generation, D-STATCOM, Power Loss Index.

1. Introduction:

The amount of power generated wasted as 10 to 13 % losses in the distribution network. The power generation by convention methods like thermal and hydro is unable to fulfill the required stipulated power. DG (Distributed generation) preferably knows as the localized generation for generating of power at the load end side. The size of DG typically varies from less than Kilowatt to tens of Megawatt. The power generated by conventional resources it is unidirectional that will flow from source to load. The integration of Distributed generation at the distribution side has several advantages like reduction power loss, decrease in carbon emission, etc.

In general, distribution systems have to meet the demands of a huge load with a variety of customer types. Due to massive power losses across the network, Share of X/R value of wire effect in severe voltage dips per unit centimeter. According to current estimates, 14 % of full power produced has been wasted during distribution. Shunt capacitors and series voltage regulators are the two traditional methods used to keep distribution system voltages within a reasonable range [1–3].

The above conventional devices have few disadvantages. In line connected voltage controllers are not capable to supply imaginary power includes very poor answer for sequential reactive power support in step by step manner as per the demand of the load [4]. In general the major disadvantage of conventional shunt capacitor is also not able to supply the demand of reactive power as per variation of the inductive load [5-7].

In order to address the aforementioned shortcomings of traditional series voltage regulators and traditional shunt capacitors, flexible alternating current transmission system (FACTS) technology incorporates power electronics for control and conversion of electrical power are installed at near to the loads. This improves performance of distribution system. The quality of the power can be raised by following the grid codes. [8].

The Parallel operated VSC type Distributed STATCOM (D-STATCOM) and i-UPQC are FACTS devices have good advantages. Compared to UPQC & i-UPQC, D-STATCOM has good merits like low losses, small in size, low harmonic distortion, resonance problem free, low harmonic distortion, and can operate continuously in step by step manner, among others [9–10]. These controllers bring increased efficiency to loads and to boost reliability. Imaginary power compensation to loads plays a crucial function for each and every FACTS device in lowering power losses, enhancing voltage regulation, and balancing the voltage under both transient and steady state conditions.

Since a few years ago, numerous researchers have been conducting studies and proposing various approaches for determining the size, kind, and ideal position of the FACTS device. The Cuckoo searching method is used by the authors in [3] to compare active power losses and determine the best location for FACTS devices. The authors of [5] suggested the ideal placement and dimensions for D-STATCOM using the immunological algorithm. The size of D-STATCOM and its ideal position are determined by authors in [6] using the particle swarm optimization algorithm. The authors of [7] use a novel hybrid model to estimate the appropriate distribution of FACTS devices. The authors of [8] provide a novel method for distributing the D-STATCOM using the firefly algorithm. Using a modified bat algorithm, the authors in [9–10] calculate where in the power system FACTS devices should be placed in order to regulate voltage. Use an algorithm like the GA-BB-BC [11] for the distribution system's optimal D-STATCOM allocation. The three basic steps of the load flow approach employed in this research for the computation of load current are sweep over the line in front and BIBC construction matrix [11].

This study introduces an improved power loss indication method for determining the appropriate range and placement of D-STATCOM. It is a productive approach for improving voltage profiles also minimizes losses in radial line. To compute line losses and voltage profiles, an analysis is performed with respect to variation of load in the radial lines. Optimization of D-STATCOM analysis decides the size and rating. High PLI values are used to select candidate buses. By adjusting for the DSTATCOM size that was gathered using the MATLAB application, four test systems are finally loaded into the candidate bus.

2. Problem formulation:

In practically, I^2R losses are major in radial line due to transmission of power over long distances. One of the important constraints is shifting the rate of transferred power as per increment and decrement of load, while keeping active power, reactive power, and voltage magnitude within a suitable range. The total real-power demand should always equal to active power generation equation, minus total real-power losses.

$$P_{G_K} = \sum_{K=1}^{n} P_{G_K} - P_L = P_D$$

$$P_{G_K} = \sum_{K=1}^{n} P_{G_K} - P_L - P_D = 0$$

$$P_{G_K} = \sum_{K=1}^{n} P_{G_K} - (P_D + P_L) = 0$$

Where,

P_L are the total transmission losses (MW),

P_D the total real-power demand (MW), and

P_{GK} the real-power generation at the K^{th} unit (MW).

Real and reactive power generation will always have upper and lower bounds at each unit. The restrictions on inequality are shown as follows:

1. As per active power generation

$$P_{G_{K(min)}} \leq P_{G_K} \leq P_{G_{K(max)}}$$

2. As per imaginary power generation

$$Q_{G_{K(min)}} \leq Q_{G_K} \leq Q_{G_{K(max)}}$$

Since transmission lines undergo loss, reactive-power limits must be measured in reference to active and imaginary power generation as well as voltage at each bus. Therefore, certain restrictions must be kept for the voltage at each bus:

$$V_{K_{(min)}} \leq V_k \leq V_{K_{(max)}}$$

Because of this, it is simple to determine the optimal approach by reducing the financial variables and meeting the limitations conditions. The main purpose of the distribution system is to maximize the safe and secure use of electrical energy; as a result, it is placed between the sub transmission system and the consumer site. Customers supply the power utilizing a variety of circuits from multiple locations, unlike gearbox and sub gearbox systems.

3. D-STATCOM location optimization algorithm:

The ideal location for D-STATCOM is chosen using the indexing power loss. Values of PLI for each bus are calculated. The potential bus for D-STATCOM position has highest PLI value since it is the most beneficial bus. Here follows procedure to calculate PLI:

Step 1: To interpret line and bus configuration of radial line.

Step 2: To analyze variation of load, it’s essential to determine the bus voltages and the power loss at every branch.

Step 3: Find the reactive power demand in all buses and execute mathematical modeling of D-STATCOM.

Step 4: Find all active power losses in all buses, inject reactive power to make up for it at all buses (excluding generator buses), and then execute the load flows.

Step 5: The equation below can help you find PLI (power loss indices).

$$\mathrm{PLI[g]} = \frac{\mathrm{P[g]} - \mathrm{Pn}}{\mathrm{Px} - \mathrm{Pn}}$$

Here g = 2, 3, 4, 5….n

Anywhere n = Total buses

P = Power loss decline

Px = maximum reduction in power loss

Pn = minimal reduction in power loss

Step 6: Choose candidate bus with peak PLI worth.

Step 7: End

Figure 1 displays the PLI (power loss indices) values for 33 bus test setups.

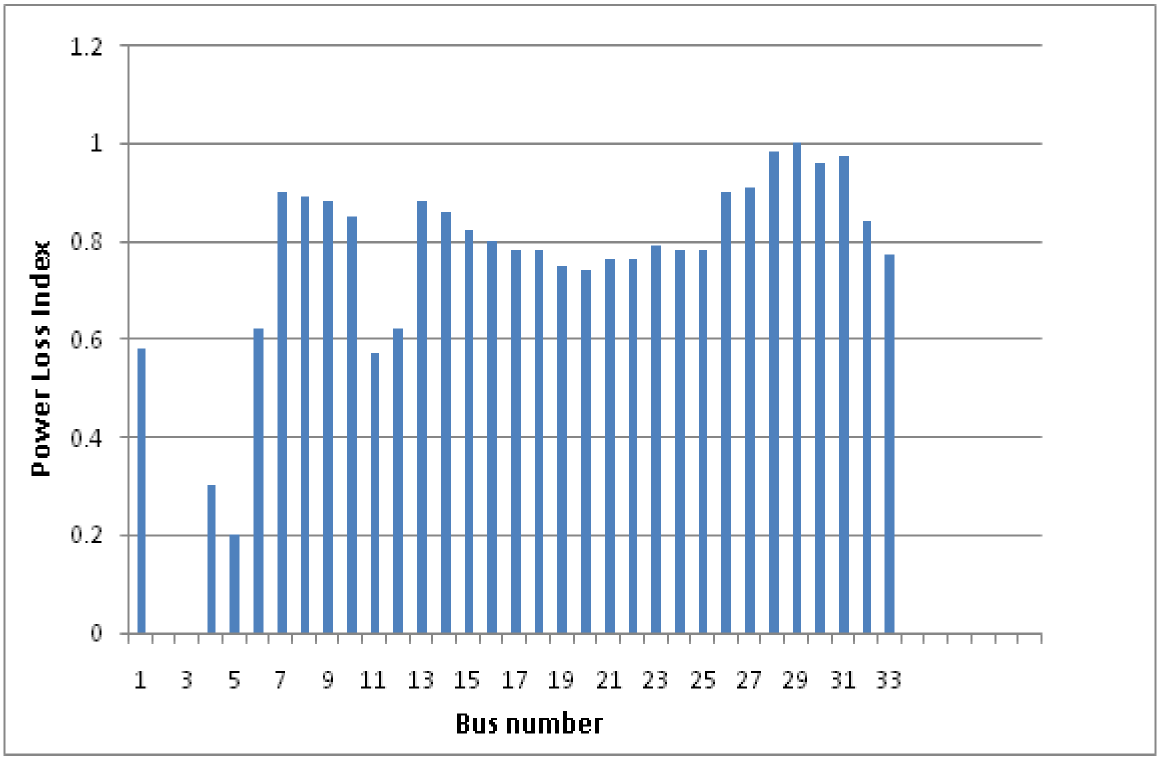

Fig.1. System using the IEEE 33 bus PLI profile

4. Proposed Approach:

An analysis of the power system network's load flow is utilized for finding the continuous state solution for 33-bus network. The load flow analysis provides information on the phase angle relation, current, real and imaginary power, and total actual energy losses in the various transmission lines. Variation of load and its analysis is crucial for the development stages of new power systems. It is crucial to combine distribution system analysis with load flow analysis to identify problems with planning, designing, operating, and controlling a system. For some applications, such the deployment of distributed generation, it necessitates repeated power flow solutions.

Due to the advancement of digital computers and their widespread application in power systems, numerous algorithms were developed around 1950. The most popular algorithms like Newton-Raphson, direct Gauss-Seidel (Z bus – matrix parameters) and indirect Gauss- Seidel (Y bus – matrix parameters) have been developed for gearbox systems and unfortunately they are not suitable for distribution systems because of its characteristics like unstable radial system load, unstable function, radial in structure, huge integer of nodes, twigs, high value of R and X values.

A. Forward and Backward propagation algorithm:

Radial networks use iterative load flow computation using a forward/backward sweep methodology. Each cycle has two computing steps. Multiple groups of computational equations will be executed progressively to analyze the fluctuation of load issue with a single station network. When calculating power flow via the branches, the initial group of expressions started at the furthest branch and worked their way backward until they reached the root node. Starting at the root node and continuing forward until the last node, the voltage magnitude and phase angle were determined separately for each node.

B. Forward propagation system:

Calculating voltage drop is essentially a forward steep approach with updates for power or current flow. Branch nodal voltages are simplified in forward sweep mode through the outermost layer inward. Advance dissemination is used to compute voltages at every bus. Voltage at the substation is changed to reflect its true value. The power in the branch has not yet altered as a result of the change in backward propagation; it is kept constant. In a forward sweep controller, the DC voltage across the capacitor can be rectified and stored at the capacitor's rated value.

C. Backward propagation system:

When power propagates backward, it moves from the last bus to the first bus. Based on the prior iteration, the revised power flow is executed. Node voltages are updated up to their real value in backward mode of operation, which does not interfere with updated voltages in forward propagation. In essence, backward propagation is a current or power flow solution with potential voltage updates to the present network nodes. It also functions as an inverter to inject currents into the line. The well-known backward sweep procedure controls the system's stability and reduces the LVRT issue. As a result, the controllability is improved so that it can match the load requirement in the node centers.

D. Implementation of forward and backward propagation algorithm:

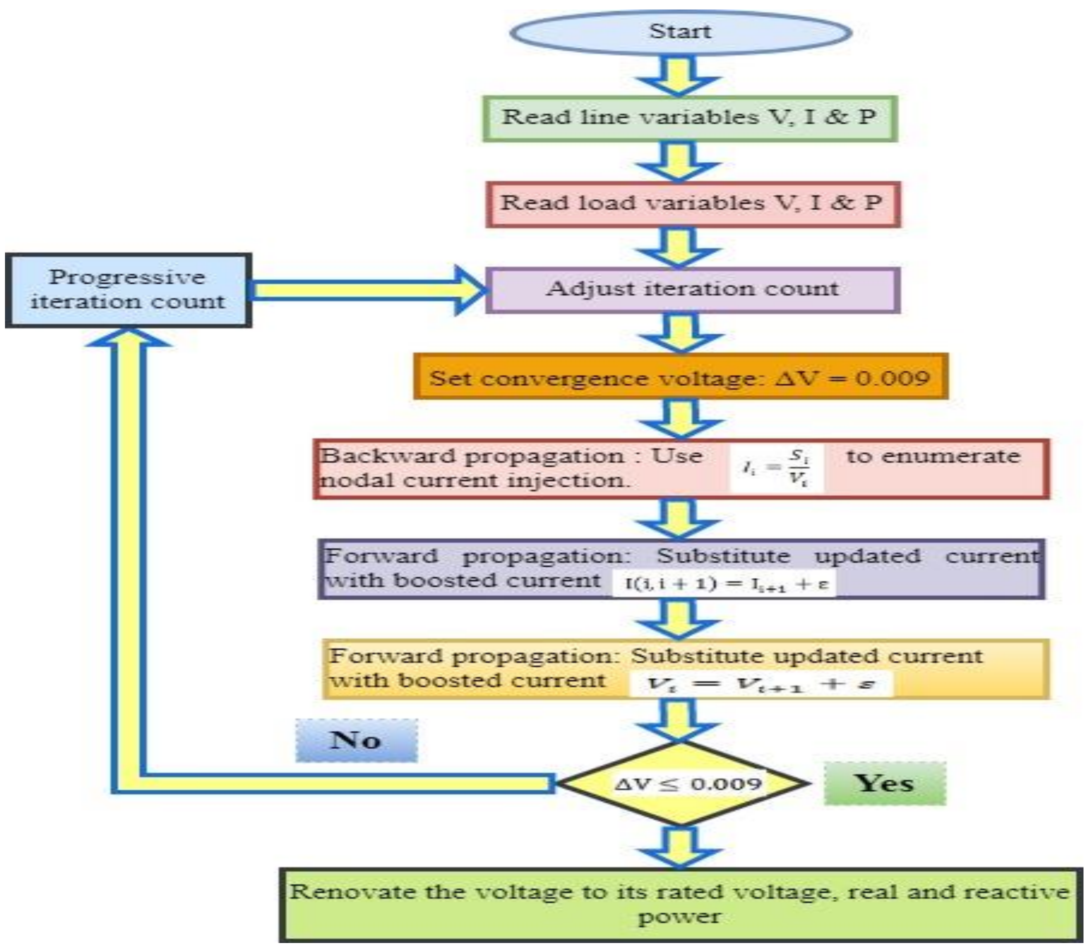

Fig .2. Flowchart of forward and backward propagation algorithm based load flow analysis at radial line System

5. Results of the simulation and discussion:

By using conventional IEEE 33 bus system assess effectiveness of this technology, and the findings show that it produces ideal size and position, both with and without the operation of DG and D-STATCOM in 4 case studies.

Case 1: Island operation of DG & D-STATCOM

Case 2: Placement of DG

Case 3: Placement of D-STATCOM

Case 4: Interconnection and interoperability with DG & DSTATCOM

The size and position of D-STATCOM are determined using the proposed optimization, which is implemented with PLI.

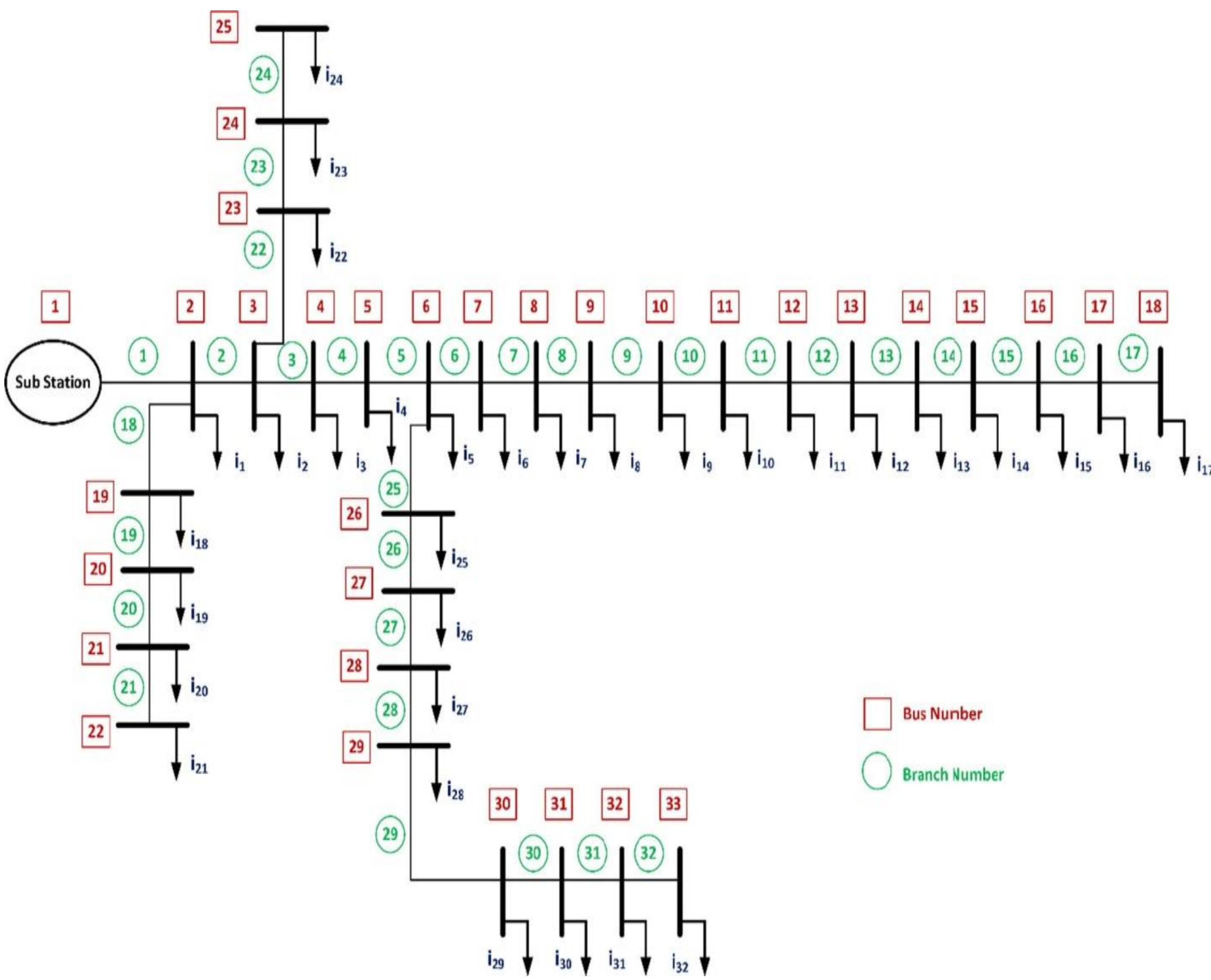

Fig.3. Radial distribution system with 33 buses

5.1. Comparative evaluation of DG and DSTATCOM combinations:

To compare various parameters of line and bus configuration from the IEEE 33-bus radial line structure, four different cases—island operation of DG and DSTATCOM, placement of DG, placement of D-STATCOM, and interconnection and interoperability with DG & D-STATCOM was used, as shown in Table 1-5. The table below compares the dimensions of the DG and D-STATCOM for the aforementioned cases. For each of the four scenarios, the number of buses with under voltage problems is counted, and total actual and reactive power losses are compared.

Table.1. IEEE 33 bus radial line and bus data.

S.NO	Sending end bus	Receiving end bus	Resistance (Ω)	Reactance (Ω)	Active power (MW)	Reactive power (MVAR)
1	1	2	0.0922	0.047	100	60
2	2	3	0.493	0.2511	90	40
3	3	4	0.366	0.1864	120	80
4	4	5	0.3811	0.1941	60	30
5	5	6	0.819	0.707	60	20
6	6	7	0.1872	0.6188	200	100
7	7	8	0.7114	0.2351	200	100
8	8	9	1.03	0.74	60	20
9	9	10	1.044	0.74	60	20
10	10	11	0.1966	0.065	45	30
11	11	12	0.3744	0.1238	60	35
12	12	13	1.468	1.155	60	35
13	13	14	0.5416	0.7129	120	80
14	14	15	0.591	0.526	60	10
15	15	16	0.7463	0.545	60	20
16	16	17	1.289	1.721	60	20
17	17	18	0.732	0.574	90	40
18	2	19	0.164	0.1565	90	40
19	19	20	1.5042	1.3554	90	40
20	20	21	0.4095	0.4784	90	40
21	21	22	0.7089	0.9373	90	40
22	3	23	0.4512	0.3083	90	50
23	23	24	0.898	0.7091	420	200
24	24	25	0.896	0.7011	420	200
25	6	26	0.203	0.1034	60	25
26	26	27	0.2842	0.1447	60	25
27	27	28	1.059	0.9337	60	20
28	28	29	0.8042	0.7006	120	70
29	29	30	0.5075	0.2585	200	600
30	30	31	0.9744	0.963	150	70
31	31	32	0.3105	0.3619	210	100
32	32	33	0.341	0.5302	60	40

Table.2. Test system results for island operation of DG & DSTATCOM

Case study	S.NO	Test system results(IEEE-33 BUS)	
Island operation of DG & D-STATCOM	1	Active power loss(KW)	202.3861
	2	Reactive power loss(KVAR)	134.9504
	3	Total power loss(KVA)	337.3365

Table.3. Test system Results with Placement of DG:

Case study	Test system results(IEEE-33 BUS) With DG Placement	
Placement of DG	Active power loss(KW)	104.4246
	Reactive power loss(KVAR)	75.3000
	Total power loss(KVA)	179.7246
	Optimal location	6
	Optimal Size(KW)	2.7587

Table.4. Test system Results with Placement of D-STATCOM:

Case study	Test system results(IEEE-33 BUS) With DSTATCOM Placement	
Placement of D-STATCOM	Active power loss(KW)	143.7635
	Reactive power loss(KVAR)	96.3128
	Total power loss(KVA)	240.0763
	Optimal location	30
	Optimal Size(KW)	1.1834

Table.5. Test system Results with Interconnection and interoperability with DG & DSTATCOM:

Case study	**Test system results(IEEE-33 BUS) With DSTATCOM Placement**	
Interconnection and interoperability with DG & DSTATCOM	Active power loss(KW)	68.1994
	Reactive power loss(KVAR)	48.2572
	Total power loss(KVA)	116.4566
	Optimal location	30
	Optimal Size(KW)	1.1834

6. Conclusion:

Today's distribution systems are a crucial area of study. Existing and new networks are given self-sufficiency for ailing electricity grids. As a result of the extremely limited power supply to these grids and the fact that more losses will lower voltage quality, active distribution networks must reduce losses.

The PLI technique, an algorithm for choosing the best locations and sizes simultaneously, is used in this work. The suggested technique evaluated with IEEE 33 bus trial arrangement headed for confirm findings. Power loss minimization is the only objective function considered in this study. The PLI technique's main advantage is that there are no settings required for implementation or control. Due to the coordination between DG and D-STATCOM, the electrical energy was improved and power outage was reduced.

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