Differential Evolution based Voltage Injection Scheme for Maintaining Constant Load Voltage

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Abstract- **Injection voltage is planned using a series voltage injection scheme to keep the desired load voltage at load end with considering load power factor as variable with source voltage as fixed and variable. This injected voltage is optimized as control variable so as to get the required voltage at load end. For this differential evolution has been used to validate the injected voltage and the obtained results are also simulated in MATLAB. For the presented work short transmission line model has been considered and In order to maintain load voltage constant, planning is done for injection voltage by considering different values of source voltage, power factor angle, active and reactive power. Planning is done for injection voltage is a kind of Dynamic Voltage restorer (DVR) used for injecting controllable voltage to keep the desired voltage, Thus injected voltage is estimated by Differential Evolution (DE) and validated by MATLAB simulation.**

Keywords— Voltage Injection, DVR, Differential Evolution (DE), Matlab Simulation.

I. INTRODUCTION

At load end usually the voltage support is achieved using reactive power injection by means of installing mechanically switched shunt capacitors connected to the primary side of distribution transformer. Switching is achieved by supervisory control and data acquisition system. With this scheme high speed transients compensation and sag correction is difficult to achieve. On load operation tap changing transformer is a costlier option for voltage control. DVR is a reliable power electronic solution for voltage regulation. Moreover DVR can also handle voltage sensitive loads.

Klempka et. al. [1] presented a central control system with Genetic algorithms used for power quality improvement. Boonchain et.al.[2] presented voltage injection scheme with DVR to mitigate voltage sag. Farhoodnea et. al. [3] presented an optimization method using firefly algorithm which addresses the sizing problem with location of DVR for power quality issues in distribution systems. Arya and Koshti [4] presented Modified shuffled frog leaping optimization algorithm utilized for optimizing DG capacity for minimizing real power loss in sub-transmission network. Koshti et.al. [5] presented scheme for selection of best locations of DG for optimizing power losses. Imran Azim et.al.[6] presented paper on use of genetic algorithm for reactive power compensation using static VAR compensation. Liserre et.al.[7] presented a new active damping technique with the use of genetic algorithm for tuning the filter. Price et.al. [8] developed a differential evolution (DE) an evolutionary technique for solving optimization problems. Arya et. al. [9] presented the DE method used for optimization of transmission losses with respect to the capacities of distributed generation for sub transmission network. DE has been utilized for solving optimization problems[10-12]

In view of above literature the presented work shows injection voltage planning by differential evolution for a short transmission line model for maintaining constant voltage across load under load at different power factor condition with two condition i.e. by keeping source voltage as fixed and variable with keeping supply frequency as constant.

II. VOLTAGE INJECTION SCHEME

The key issues for power qualities are voltage sag, swell and harmonics in which most affecting disturbance is voltage sag. To remove such problems the power electronic based solution i.e. DVR is utilized which is an efficient and reliable solution for voltage control. DVR is usually installed at the point of common coupling (PCC). It is also added in line for voltage harmonic compensation. The DVR's purpose is to inject a controlled voltage to overcome power quality problems discussed above. It is achieved by voltage source converter and injection transformer. DVR has three modes of operation that is protection mode, standby mode, injection/boost mode.

A. Injected voltage planning

Injected voltage can be planed so as to have constant received end voltage to 230 volts RMS value. So this is formulated as optimization problem to get receiving end voltage constant as follows-

The complex power at load end

$$S_R = V_R I_R^* = P + jQ$$

Where, Load end voltage V_R = 230 V

V_S = Source voltage

θ_S = Source voltage phase angle

I_S = Source current

I_R = load current

Z_S = Transmission line impedance

$$I_R = \frac{P - jQ}{V_R \angle 0°}$$

$$V_S + V_{inj} = I_R\left(Z_S\right) + V_R$$

$$V_{inj} = V_R + \left(\frac{P - jQ}{V_R}\right) Z_S - V_S \angle \theta_S$$

$$V_{inj} = a + jb$$

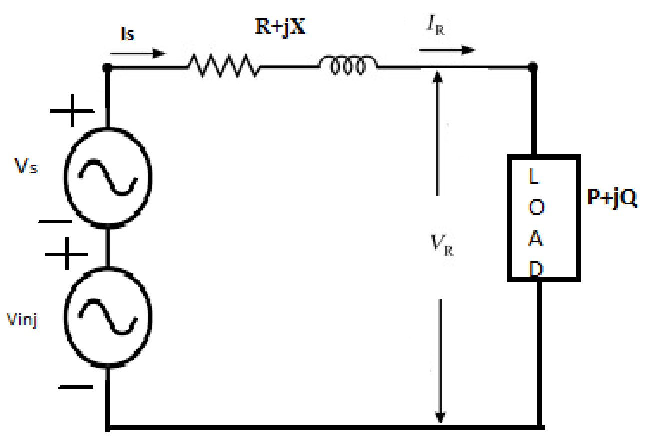

Fig-1. Short transmission line model with injected voltage planning

$$V_R = V_S\angle\theta s + a + jb - \left(\frac{P - jQ}{230}\right) Z_S$$

$$V_R = f\left(V_{inj}\right) = f\left(a + jb\right)$$

$$\min f\left(V_{inj}\right) = \min\left|V_R - 230\right| \qquad (1)$$

Where,

Injected voltage $V_{inj} = a + jb$

Therefore V_{inj} is treated as control variable and values of a and b can be optimized using differential evolution as discussed in next section for getting load voltage constant at 230 V with respect to the variation in load power factor. For the above optimization problem the frequency of source and load voltage is assumed as fixed to 50 Hz.

Thus injected voltage can be planned for the load at different power factors conditions for the two cases when

i) V_S is constant

ii) V_S is variable

III. DIFFERENTIAL EVOLUTION FOR INJECTED VOLTAGE PLANNING

Differential evolution [8] an evolutionary technique is used to solve optimization problems. An algorithm has been developed for optimizing injected voltage as given in equation (1) as follows-

Step-(i): *'M'* initial vectors are generated for control variables as follows -

$$x_{ij}^{(0)} = x_{j,\min} + (x_{j,\max} - x_{j,\min}) rand_j \qquad (2)$$

$$S^{(0)} = [V_{inj,1}{}^{(0)}, V_{inj,2}{}^{(0)}, \ldots\ldots.. V_{inj,M}{}^{(0)}]$$

$$V_{inj,i}{}^{(0)} = [a_i^{(0)}, b_i^{(0)}]^T \qquad \text{for } i=1,\ldots, M$$

Step-(ii): A mutant vector $\underline{V}_i^{(k)}$ is calculated as-

$$V_i^{(k)} = V_{inj,base}{}^{(k)} + \sigma(V_{inj,p}{}^{(k)} - V_{inj,q}{}^{(k)}) \text{ for } i=1,\ldots,M \qquad (3)$$

Where, σ is a scaling factor in range [0,1], and $p \neq q \neq \text{base}$.

Step-(iii): Control variables are brought within limit by [9], when some of the control variables crosses the limits in mutant vector.

Step-(iv): Trial vectors $t_i^{(k)}$ are produced with a uniform crossover strategy.

Step-(v): Receiving end voltage is estimated for target vector and trial vector, following criteria is used to select vector as follows-

$$V_{inj,i}{}^{(k+1)} = \begin{cases} t_i^{(k)} & \text{if } f(t_i^{(k)}) \le f(V_{inj,i}{}^{(k)}) \\ V_{inj,i}{}^{(k)} & \text{otherwise} \end{cases} \qquad (4)$$

Step-(vi): Repeat procedure from step-(ii) to step-(v) till convergence. The algorithm will be run for specified maximum number of generation (K_{max}) and may be terminated before this if convergence is observed.

IV. RESULT

To maintain load voltage constant under different load condition is critical due to voltage drop involved in series impedance of transmission line. In order to maintain load voltage constant, planning is done for injection voltage by considering different values of source voltage, load power factor angle, active and reactive power. Planning done for injection voltage is validated by DE and MATLAB simulation. A short transmission line has been considered with impedance $Z_S = 2{+}j16\,\Omega$ for the purpose.

DE technique has been used to obtain the optimal values of control variables i.e. injected voltage $V_{inj} = a + jb$ for maintaing constant voltage across load with respect to the above mentioned condition. The following control parameters are used for optimum results using DE is given as, M=10, scale factor $\sigma = 0.6$ with K_{max}=500. Simulation Diagram with series voltage injection is constructed in MATLAB as shown in Fig-2. MATLAB Simulink model is also used to validate the calculations for injection voltage.

A. Simulation Diagram

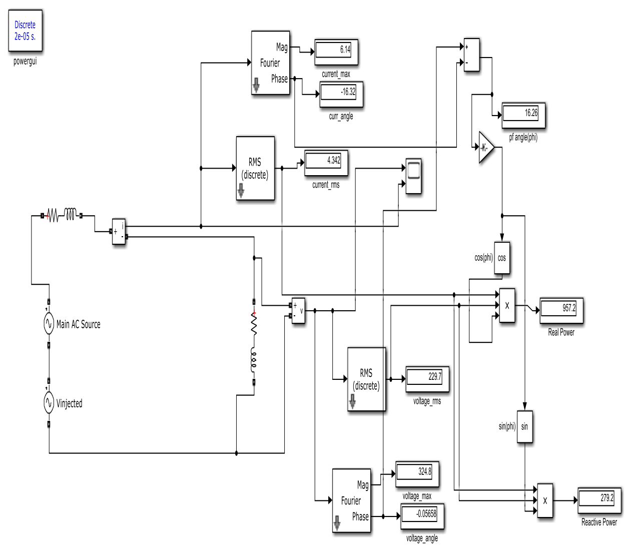

Fig-2 Simulation diagram for voltage injection planning

B. Tables.

Table I(A), Table I(B) and Table I(C) shows the injection voltage planning when load is considered as active and reactive power at different power factor where load is 1KVA. This tables show the series injection voltage for different cases.

Table-I(A) shows the KVA load is fixed as 1 KVA whereas load power factor is changing for constant source voltage= 230 V and 50 Hz frequency. Similarly the injected voltage is obtained using DE as optimization problem as discussed in equation (1) and the results are shown in Table-I(B) and the obtained results are also validated and simulated in MATLAB as shown in Table-I (C). The obtained results found are in close agreement.

Table II, table III, table IV, table V, table VI shows the voltage injection planning when source voltage is variable at variable power factor angle and fixed supply frequency 50 Hz.

(7.17)

Table II shows the injection voltage planning for variable source voltage i.e 180 volts to 250 volts at load current $4.34\angle -60^o$ amperes.

Table III shows the injection voltage planning for variable source voltage i.e 180 volts to 250 volts at load current $4.34\angle-53°$ amperes.

Table IV shows the injection voltage planning for variable source voltage i.e 180 volts to 250 volts at load current $4.34\angle-45°$ amperes.

Table V shows the injection voltage planning for variable source voltage i.e 180 volts to 250 volts at load current $4.34\angle-36°$ amperes.

Table VI shows the injection voltage planning for variable source voltage i.e 180 volts to 250 volts at load current $4.34\angle-16°$ amperes.

In all above cases injection voltage is obtain by using DE as optimization problem as discussed in equation (1). The obtained results found are in close agreement.

Table-I (A) Injection voltage for different power factors

Load KVA	Power factor Lagging	Current (Ampere)	Injection voltage ($Vinj$)volts
1	0.5	$4.34\angle-60^o$	$64.47+27.20j$
1	0.6	$4.34\angle-53°$	$60.68+34.85j$
1	0.707	$4.34\angle-45°$	$53.23+42.96j$
1	0.8	$4.34\angle-36°$	$47.83+57.07j$
1	0.98	$4.34\angle-16°$	$27.70+64j$

Table-I(B) Injection voltage planning by Differential Evolution for different power factors.

Load KVA	Power factor Lagging	Current (Ampere)	Injection voltage ($Vinj$) by Differential Evolution (volts)
1	0.5	$4.34\angle-60^o$	$64.47+27.19j$
1	0.6	$4.34\angle-53°$	$60.67+34.85j$
1	0.707	$4.34\angle-45°$	$53.20+42.96j$
1	0.8	$4.34\angle-36^o$	$47.83+57.10j$
1	0.98	$4.34\angle-16^o$	$27.68+64j$

Table-I(C).Injection voltage planning validation in matlab simulation for different power factors.

Load KVA	Power factor Lagging	Current (Ampere)	Injection voltage ($Vinj$) by MATLAB (volts)
1	0.5	$4.34\angle-60^o$	$64.47+27.19j$
1	0.6	$4.34\angle-53°$	$60.67+34.85j$
1	0.707	$4.34\angle-45°$	$53.20+42.96j$
1	0.8	$4.34\angle-36^o$	$47.83+57.10j$
1	0.98	$4.34\angle-16^o$	$27.68+64j$

Table II. Voltage injection planning when source voltage is variable and load current is $4.34\angle-60^o$ in amperes

Source voltage (Vs) (Volts)	Load Current (Amperes)	Injection voltage ($Vinj$) (Volts)	Injection voltage ($Vinj$) (volts) by Differential evolution
$180\angle10°$	$4.34\angle-60^o$	$117.22-4.053j$	$117.21-4.053j$
$190\angle10°$	$4.34\angle-60^o$	$107.36-5.79j$	$107.35-5.79j$
$200\angle10°$	$4.34\angle-60^o$	$97.51-7.52j$	$97.51-7.52j$
$210\angle10°$	$4.34\angle-60^o$	$87.65-9.26j$	$87.64-9.26j$
$220\angle10°$	$4.34\angle-60^o$	$77.81-10.99j$	$77.83-10.99j$
$240\angle10°$	$4.34\angle-60^o$	$58.12-14.47j$	$58.12-14.47j$
$250\angle10°$	$4.34\angle-60^o$	$48.24-16.20j$	$48.24-16.20j$

Table III. Voltage injection planning when source voltage is variable and load current is $4.34\angle-53°$ in amperes

Source Voltage (Vs) (Volts)	Current (Amperes)	Injection Voltage ($Vinj$) (Volts)	Injection Voltage ($Vinj$) (volts) by differential evolution
$180\angle10°$	$4.34\angle-53°$	$113.43+3.60j$	$113.43+3.60j$
$190\angle10°$	$4.34\angle-53°$	$103.55+1.86j$	$103.55+1.86j$
$200\angle10°$	$4.34\angle-53°$	$93.71+0.128j$	$93.71+0.128j$
$210\angle10°$	$4.34\angle-53°$	$83.87-1.81j$	$83.87-1.81j$
$220\angle10°$	$4.34\angle-53°$	$76.57-1.81j$	$76.57-1.81j$
$240\angle10°$	$4.34\angle-53°$	$54.32-6.81j$	$54.32-6.81j$
$250\angle10°$	$4.34\angle-53°$	$44.47-8.55j$	$44.44-8.55j$

Table IV. Voltage injection planning when source voltage is variable and load current is $4.34\angle-45°$ in amperes

Source voltage (Vs) (Volts)	Load Current (Amperes)	Injection voltage ($Vinj$) (Volts)	Injection Voltage ($Vinj$) (volts) by differential evolution
$180\angle10°$	$4.34\angle-45°$	$107.97+9.9j$	$107.975+9.9j$
$190\angle10°$	$4.34\angle-45°$	$98.14+9.9j$	$98.13+9.9j$
$200\angle10°$	$4.34\angle-45°$	$88.42+8.23j$	$88.42+8.23j$
$210\angle10°$	$4.34\angle-45°$	$78.52+6.49j$	$78.52+6.49j$
$220\angle10°$	$4.34\angle-45°$	$68.68+4.76j$	$68.68+4.76j$
$240\angle10°$	$4.34\angle-45°$	$48.58+1.28j$	$48.58+1.28j$
$250\angle10°$	$4.34\angle-45°$	$39.09-0.44j$	$39.09-0.44j$

Table V. Voltage injection planning when source voltage is variable and load current is $4.34\angle-36^o$ in amperes

Source Voltage (Vs) (Volts)	Current (Amperes)	Injection Voltage ($Vinj$) (Volts)	Injection Voltage ($Vinj$) (volts) by differential evolution
$180\angle10°$	$4.34\angle-36^o$	$100.57+19.8j$	$100.57+19.8j$
$190\angle10°$	$4.34\angle-36^o$	$90.75+18.08j$	$90.75+18.08j$
$200\angle10°$	$4.34\angle-36^o$	$80.57+16.34j$	$80.57+16.34j$
$210\angle10°$	$4.34\angle-36^o$	$71.02+14.61j$	$71.02+14.61j$
$220\angle10°$	$4.34\angle-36^o$	$61.15+12.87j$	$61.15+12.87j$
$240\angle10°$	$4.34\angle-36^o$	$41.25+9.40j$	$41.25+9.40j$
$250\angle10°$	$4.34\angle-36^o$	$31.63+7.66j$	$31.63+7.66j$

Table VI. Voltage injection planning when source voltage is variable and load current is $4.34\angle-16^o$ in amperes

Source Voltage (Vs) (Volts)	Current (Amperes)	Injection voltage (Vinj) (Volts)	Injection voltage (Vin)j (volts) by differential evolution
$180\angle10°$	$4.34\angle-16^o$	$80.21+33.10j$	$80.22+33.10j$
$190\angle10°$	$4.34\angle-16^o$	$70.37+31.36j$	$70.37+31.36j$
$200\angle10°$	$4.34\angle-16^o$	$60.52+29.62j$	$60.52+29.62j$
$210\angle10°$	$4.34\angle-16^o$	$50.67+27.89j$	$50.66+27.89j$
$220\angle10°$	$4.34\angle-16^o$	$40.82+26.15j$	$40.82+26.15j$
$240\angle10°$	$4.34\angle-16^o$	$21.25+22.68j$	$21.25+22.68j$
$250\angle10°$	$4.34\angle-16^o$	$11.28+20.94j$	$11.28+20.94j$

CONCLUSION

In order to maintain load voltage constant, planning is done for injection voltage by Differential Evolution considering different values of source voltage, load power factor angle at constant source frequency and validated in MATLAB simulation.

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