Cost Optimization of SRF Based MC-DVR Using GA-PSO

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Abstract

This paper deals with cost optimization of Multi converter-DVR in distribution systems with a design SRF-based control in three phase system under different load considerations to improve power quality by using series power conditioner with multi voltage source converters. It is desirable to have a cost optimization of the SRF-based MC-DVR. Since the optimal angle at which series injected voltage as to have minimum VA loading of MC-DVR. Which leads to optimization of cost according to Siemens data base. The optimal angle at which series voltage has to be injected so as to have minimum VA loading of MC-DVR are computed by genetic algorithm (GA) and Particle Swarm Optimization (PSO) technique.

Keywords:

Index Terms□Active power filter (APF), Synchronous reference frame (SRF), Genetic algorithm (GA), Particle Swarm Optimization (PSO) and Multi converter dynamic voltage restorer(MC-DVR).

1.INTRODUCTION

In present days due to increased usage of induction loads and switched apparatus in domestic and industries, leads to more no of power-quality (PQ) problems [2], such as harmonics, Voltage flickers, Voltage sags, unbalanced voltages, lightning strokes on transmission lines, switching of capacitor banks. Some sensitive loads are requiring a pure A.C supply voltage for proper functioning of load [1]. To meet the standard limits of active and reactive power levels some sort of compensation is required.

In olden days to meet these demands FACTS devices have been used. A unified power-quality conditioner (UPQC) [4] is the extension of the unified power-flow controller (UPFC) [5] concept at the distribution level. Voltage and current imperfection can be corrected by using shunt and series active power filters [6]–[8]. Recently devices such as an interline power-flow controller (IPFC) [9] and the generalized unified power-flow controller (GUPFC) [10] are in recent application. The aim of the above devices is to control the power flow of entire line rather than sub network or portion of line.

The paper presents a new concept called the synchronous-reference-frame (SRF) [11]-[13] based control of multiconverter dynamic voltage restorer[14] (MC-DVR) is presented. It employs a common dc capacitor C_{dc} which consist of two series VSCs (VSC-1 and VSC-3) connected back to back. The VSCs are 3-level (H-bridge) inverters which will work independently and they work on the output feedback Control [15] which is used to find the switching times above inverters. Such that accurate tracing there bus voltages and currents can be as per requirement. Here feeder1 employs VSC1 in series with PCC bus-1 and feeder2 employs VSC3 in series with PCC bus-2 as shown in fig.1. All the VSCs are formed by combination of reactor (L_f), ac filter capacitors (C_f) and three phase converters in to prevent the flow of the harmonic currents into the distribution system generated due to switching at the each phase of PCC. The voltages at PCC bus1 and bus2 along with load voltage are regulated by MC-DVR. It also regulates against voltage sags, swells and compensation of nonlinear load against harmonic content (i_h).After design of SRF-Based[11]-[12]MC-DVR, comparison of VA loading MC-DVR has been done based on the quadrature [11] and in-phase voltage injection by the series active filters of the MC-DVR in [13]. Minimum VA loading of the MC-DVR has also been achieved with the voltage injection by series active filter at an optimum angle with respect to source voltage [14]-[15]. However, the effects of harmonics in both source voltages and load currents have not been considered in literature [11]-[16]. In this paper, the effects of both source voltage and load current harmonics have been considered and the VA loading of MC-DVR is minimized by injecting a series active filter voltage at an optimum angle with respect to the sag voltage. The IEEE–519 standard limits of 5% on Total Harmonic Distortion (THD) in voltage or current is set on the THD of source currents and load voltages after compensation. The proposed methodology ensures that, even with the minimum VA loading [18]-[19]. Genetic algorithm (GA) [21] and Particle Swarm Optimization technique (PSO) [22]- [24] is utilized as a tool for evaluating the optimum angle of voltage injection with constraints on THD of source currents and load voltages. Simulation results on a power distribution system are carried out and results are presented.

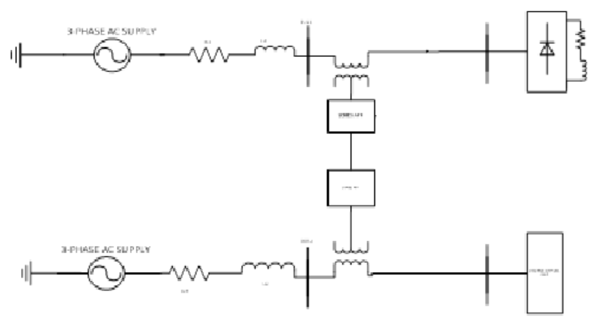

Fig.1.The single line diagram of conventional MC-DVR

2. System Representation

2.1 MC-DVR dynamic model

This section presentsthe MC-DVR mathematical modelling used in the development of state space model. Theconsidered electrical circuit is a two feeder, three-phase three-wire system.
Fig.1 shows with internal connections of the MC-DVR, with VSCs, load and the power network.The VSCs are used for injection of controllable voltage $\mu_1 V_{dc,}$ and $\mu_2 V_{dc}$ in order to control load voltage and PCC bus voltages under the closed loop

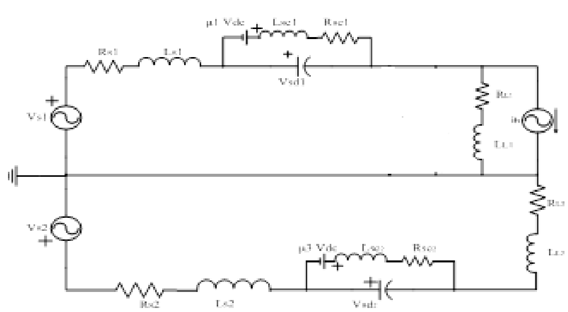

Fig.2.The single phase equivalent circuit of MC-DVR compensated parallel distribution system

The dc link voltage may be self-supported by a dc link capacitor for the case of MC-DVR. The Fig.2 is the single line diagram of of conventional MC-DVRcompensated parallel distribution system. The Filter across the both series inverter is representedbyL_{se1} C_{se1}andL_{se2} C_{se2}.
The switching loss of inverter and the copper losses of the connecting transformer are represented by a resistanceR_{se1}andR_{se2}. R_{s1} and$L_{s1}$are feeder1 resistance and inductance R_{s2} and $L_{s2}$are feeder2 resistance and inductance . Nonlinear load i_h with $R_l L_l$ load on feeder1 and feeder2 having sensitive loadR_{l2} L_{l2}. The VSC$_1$ and VSC$_2$ are supplied by common capacitor, and the voltage across each capacitor is denoted by V$_{dc}$.
By using the Kirchhoff laws in the above equivalent circuit, state space model formulated.

$$L_{s1}\frac{di_1}{dt} = -R_{s1}i_1 + V_{sd1} - V_{s1} + V_{l1} \quad (1)$$

$$L_{se1}\frac{di_2}{dt} = -R_{se2}i_2 - V_{sd1} + u_1V_{dc} \quad (2)$$

$$L_{l1}\frac{di_4}{dt} = -R_{l1}i_4 + V_{l1} \quad (4)$$

$$C_{se1}\frac{dV_{sd1}}{dt} = i_2 - i_1 \quad (5)$$

$$L_{s2}\frac{di_5}{dt} = -R_{s2}i_5 + V_{sd2} - V_{s2} - R_{l2}i_5 \quad (7)$$

$$L_{se2}\frac{di_6}{dt} = -R_{se2}i_6 - V_{sd2} + u_3V_{dc} \quad (8)$$

$$C_{se2}\frac{dV_{sd2}}{dt} = i_6 - i_5 \quad (9)$$

Where μ_1, μ_2 and μ_3 represent the duty ratio of the control variables of series and shunt VSCs.

3. Switching Strategy

3.1 Switching Control of series active power filter
The proposed Series APF control strategy is aimed to controlled voltage source and generates mainly to obtain constant load terminal voltage at the desired point at require level.

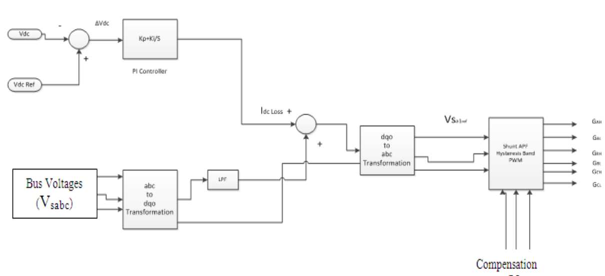

Fig.3. SRF Based Controlled Series Active Power Filter

The difference of the supply voltage and the ideal load voltage is compensate by injecting voltage by the series APF. These injected voltages cancel out the distortions in supply voltages. Fig.3 shows series APF block diagram. The synchronous reference (dq0) frame consists of detected source voltage.

$$v_{s\_dqo} = T_{abc}^{dq0} v_{s\_abc} \quad (10)$$

The instantaneous source voltages and include both oscillating components ($\widetilde{v_{s_d}}$and$\widetilde{v_{s_q}}$) and average components ($\overline{v_{s_d}}$and$\overline{v_{s_q}}$) and under unbalanced source voltage with harmonics. The source voltage negative-sequence components and harmonic are present in oscillating components ($\widetilde{v_{s_d}}$and $\widetilde{v_{s\_q}}$) under distorted load conditions. The objective of maintaining constant source voltage is done series APF even under unbalance conditions. Therefore, the expected load voltage in the synchronous dqo reference frame ($v_{l\_dqo}^{exp}$) assume to be constant.

$$v_{l\_dqo}^{exp} = T_{abc}^{dq0} v_{l\_abc}^{exp} \quad (11)$$

Here the *abc* reference frame ($v_{l\_dqo}^{exp}$) represents assumed load voltages and synchronous dqo reference frame represents compensating reference voltage ($v_{cf\_dqo}^{ref}$) and given by

$$v_{cf\_dqo}^{ref} = v_{s\_dqo} - v_{s\_dqo}^{exp} \quad (12)$$

By using SPWM voltage control technique dqo compensating reference voltage is then transformed back into the *abc* reference frame.

Total VARating of the Multi Converter-DVR:

Fig. 4 shows the Phasor diagram of the operation of the MC-DVR. The source voltages of feeder1 and feeder2 are V_{s1} and V_{s2}, the load voltages are $V_{L1}$and V_{L2} and load currents in both feeders$are I_{L1} and I_{L2}$ respectively. The load angle$\O_{L1} and \O_{L2}$ correspond to per unit sags and k_1 and k_2 are magnitudes of voltage sags to be compensated at feeders1 and2. Considering the MC-DVR to be ideal. Therefore, the input active current at Feeder I can be expressed by

$$P_{S1} = V_{S1} * I_{S1} = V_{L1} * (1 - \mathrm{k}_1) * I_{S1} \quad (13)$$

$$P_{L1} = V_{L1} * I_{L1} * \cos \o_{L1} \quad (14)$$

$$P_{S1} = P_{L1}$$

$$I_{S1} = \frac{I_{L1} * \cos \o_{L1}}{(1 - k_1)} \quad (15)$$

The feeder1 active power demand is calculated as

$$V_{s1} I_{s1} = V_{L1} * (1 - \mathrm{k}_1) * I_{S1}$$

Where $I_{S1} is$source current in feeder1 and given by

$$I_{S1} = \frac{V_{L1}\, I_{L1} \cos \O_{L1} + k_2 V_{L2}\, I_{L2} \cos \O_{L2}}{V_{L1}(1 - \mathrm{k}_1)}$$

The expression for Voltage injected by the series VSC in feeder1

$$v_{inj}^{1} = \sqrt{((V_{L1} \cos(\theta_{L1}) - v_{s1}^{1})^2 + (V_{L1}\, sin\theta_{L1})^2)} \quad (16)$$

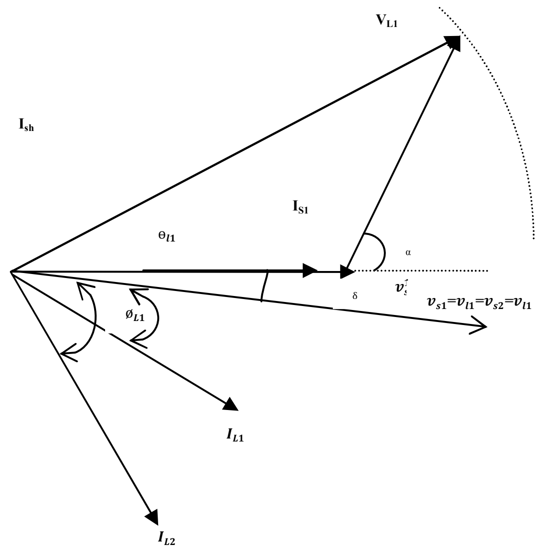

Fig. 4.Phasor diagram of the MC-DVR with voltage sag.

Where

$$\tan\alpha = \left(\frac{V_{L1}\sin\theta_{L1}}{V_{L1}\cos\theta_{L1} - v_{s1}^{1}}\right) \quad (17)$$

$$\therefore v_{inj}^{1} = (1-\mathrm{k}_1)\, V_{L1}\tan\alpha$$

Hence series VSC power rating is

$$= \begin{bmatrix} (1-\mathrm{k}_1)\, V_{L1}\tan\alpha \left(\frac{I_{L1}\cos\emptyset_{L1}}{(1-\mathrm{k}_1)} + \frac{k_2 V_{L2}\, I_{L2}\cos\emptyset_{L2}}{V_{L1}(1-\mathrm{k}_1)}\right) \\ +(THD)^{\wedge}0.5 \end{bmatrix} (18)$$

Hence power rating of the series VSC in feeder2 can be obtained in feeder2 injected voltage is almost equal to the $k_2 V_{L2}$ (where$k_2 = 1$). Therefore the expression for series –VSC power rating in feeder2 is

$$S_{sr} = v_{inj2} I_{S2} = V_{L2}\, I_{S2} \quad (19)$$

By adding equ (18) and (19), the total VA rating of overall MC-DVR can be obtained.

$$\mathrm{s}_{\mathrm{MC-DVR}} = S_{sr1} + S_{sr2} \quad (20)$$

The total VA loading of UPQC is then the function of $\mathrm{k}_1, \mathrm{k}_2$,$\emptyset_{L1}$, $\emptyset_{L2}$, θ_{L1} , total harmonic distortions THD_{iL1} , THD_{Vs1} load currents I_{L1} , $I_{L2}$and rated fundamental voltage V_{L1} , V_{L2}. In this function exceptθ_{L1}, remaining all the variables are system dependants. Therefore, the function value i.e., total VA loading of UPQC is controlled by varyingθ_{L1} . This can be expressed asa standard optimization problem as given below

$$f(\theta_{L1}) = S_{MC-DVR} \quad (21)$$

Where subject to -90º <θ_{L1}< 90º
$\theta_{L1}$is the control variable with respect to which$f(\theta_{L1})$ the has to be minimized.

The range of cost of the major flexible ac transmission systems (FACTS) devices is taken from the Siemens database. It has been mathematically formulated as

Minimize $I_{cost} = c_{MC-DVR} * \mathrm{s_{MC-DVR}}*1000$
c_{MC-DVR}= 0.0003* $\mathrm{s_{MC-DVR}}^{2}$- 0.2691*$\mathrm{s_{MC-DVR}}$ + 188.22

Minimization cost of

$f(I_{cost}) = c_{MC-UPQC} * \mathrm{s_{MC-UPQC}} *1000$ (22)

$S_{MC-DVR}$is the control variable with respect to which$f(cost)$ the has to be minimized, where S_{MC-DVR} is dependent the control variableθ_{L1}.
Where I_{cost} is the optimal installation cost of MC-DVR, c_{MC-DVR} represents cost of installation of the MC-DVR in U.S/KVA and $\mathrm{s_{MC-DVR}}$ represents the operating range of the MC-DVR in volt amperes.

4. OPTIMIZATION OF COST &VA LOADING BY USING GA-PSO

Case A: Optimization of function by using GA

Genetic algorithm involves a set of solutions called population, which is modified and repeatedly continuously. According to this algorithm at every iteration individuals known as parents are selected from the current population. These parents are then used in the process of reproduction that is producing children for the next generation. The candidate solution are represented by chromosomes, which are strings of fixed length. The best member of each population is expressed using a fitness or objective function. Taking a random initial population, GA function in a cycle or iterative procedure. These cycles are called generations. Each generation consists of the following steps:

- Every member in the population is calculated using an objective or fitness function
- The population is subjected to a continuous iteration process where in reproduction takes place for each iteration. one or more parents are randomly chosen for the reproductive process. However the strings having greater fitness values have higher chances of contributing to production of off spring.
- The production of offspring is accomplished by applying genetic operators such as mutation and cross-over to the parents.
- The offspring in turn is included in the population and the procedure is repeated.

Table 1
Parameters and values of genetic algorithm

Parameters	Values
Population size:	200
No of Iteration:	200

The parameters of genetic algorithm are shown in table I, now the equation (21)& (22) is optimized by using genetic algorithm and the optimal values of angle, VA loading and installation cost are tabulated in table.III

Case B: Optimization of function by using PSO

Particle swarm optimization is inspired by the sociological behaviour of bird flocking and fish schooling, is an optimization technique based on population. This method predicts behaviour of all particles, corresponding to various constraints and objectives and thus determines solution to optimization problem in search space

During the execution of PSO algorithm for every iteration of the particle, the each particle of velocity is modified based on the it's current velocity and its distance from personal best position "*pbest*" and global best position "*gbest*" according to

v_i^{n+1} = w (n)*v_i^n + c_1* rand1 ( )*($pbest_i^n$ - x_i^n) + c_2* rand2 ( )*($gbest_i^n$ - x_i^n)

After the velocity of each particle update is done, each particle move to their new positions according to

$x_i^{n+1} = x_i^n + v_i^{n+1}$

Considering minimization function, then the personal best ($pbest_i^n$) position at the next time step n+1, is calculated as

$$pbest_i^n = \begin{cases} pbest_i^n ; & \text{if } f(x_i^{n+1}) > pbest_i^n \\ x_i^{n+1} ; & \text{if } f(x_i^{n+1}) \leq pbest_i^n \end{cases}$$

Where 'f' is the fitness function.
The global best $gbest_i^n$ position at time step is calculated as

$$gbest_i^n = \min(pbest_i^n)$$

∴ $pbest_i^n$ is the the individual particle best position
The parameters of particle swarm optimization are shown in table II, now the equation (21)& (22) is optimized by using PSO and the optimal values of angle, VA loading and installation cost are tabulated in table.III

Table II
Pso Parameters

Parameter Value	Value
Number of Particles	200
Maximum inertia weight	0.9
Minimum inertia weight	0.4
C_1 and C_2	1.43 and 0.43
Number of iterations	50

In case of voltage sag occurs at only feeder1, the per unit value of sag k_1 where k_1 is 0.3, with the given below system parameters the total VA loading of MC-DVRand installation cost is expressed as a function of θ_{L1}as shown in equations (21)& (22) are optimized by using GA and PSO. Theoptimal angle at which series voltage has to be injected so as to have minimum VA loading and cost of MC-DVR are computed by genetic algorithm (GA) and Particle Swarm Optimization (PSO) technique as shown in table III.

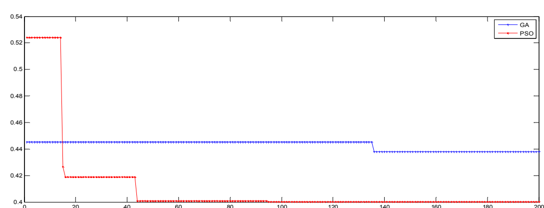

Fig. 5. VA loading Vs No of iterations

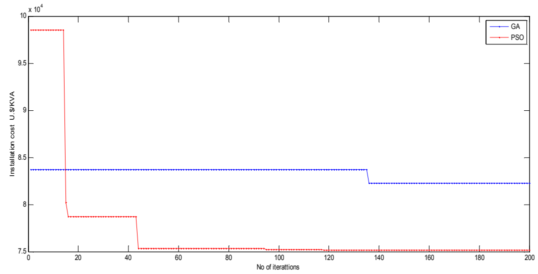

Fig. 6. Installation cost Vs No of iterations

Table III

	VA Loading (p.u)	θ_{L1} (degree)	v_{inj} (p.u)	Angle of injection α (degree)	f(I_{cost}) *10^3 (U.$/KVA)
By using PSO	0.4001	8.68	0.15	20.68	82.89
By using GA	0.4378	2.36	0.20	26.89	75.18

5. Simulation Results

In the proposed analysis i.e. PSO-SRF Based MC-DVRextensive case study using simulation in MATLAB/SIMULINK is done and simulation results on parallel distribution power system related to performance of the proposed SRF-Based MC-DVR system is as shown.The table IV shows parameters used in the proposed analysis

Table IV

System Parameters	Values
System frequency (*f*)	50HZ
Rated voltage	380V(rms, Phase-Phase)
R_{s1} andL_{s1}	0.6Ω and 0.1mH
R_{s2} andL_{s2}	0.6Ω and 0.1mH
Nonlinear Load	An Universal bridge consisting of resistor (10) Ω and R-L Load(10Ω and 3mH)
Linear Load-1	A three-phase resistive Load (10) Ω
Linear Load-2	A three-phase R-L Load (10 Ω and 10mH)
VSC-1 and VSC-2 Series T/F (T_1andT_3)	4kva,200/180,50Hz,10% leakage reactance
T/F (T_1andT_3)	Reactance
Power losses in VSC-1,VSC-2,	R_{f1}=0.1Ω,R_{f2}=0.1
DC Capacitor(C_{DC})	2,800μF

Case: A Voltage sag and swell on both feeders

A three-phase feeder 1 distribution system is having single phase voltage source$v_1(t)$of 50HZ frequency is

$$v_1(t)= \left(v_{m1} sin(wt) + \frac{v_{m2} sin(5wt)}{5}\right) \quad (23)$$

This is has 5thorder harmonics with sag at 0.1s to 0.2s and sudden change load at 0.5s to 0.7s. Athree-phase feeder 2 distribution system is having single phase voltage source$v_2(t)$of 50HZ frequency is

$$v_2(t)= \left(v_{m1} sin(wt) + \frac{v_{m2} sin(7wt)}{7}\right) \quad (24)$$

7thorder harmonics, sag occurs at 0.15s to 0.25s, swell occurs at 0.26s to 0.3s.The behavior of distribution system SRF-Based MC-DVR has been shown in. fig. 7. The three-phase unbalanced PCC bus voltages ($V_{s1}$and V_{s2}) *and* Load voltages (V_{L1} and V_{L2}) are represented. It consist of Nonlinear Load/Linear Load (L_1)a Universal bridge consisting of resistor (10) Ω and R-L Load (10Ω and 3mH). The critical load (L_2) contains a balanced RL load (10 Ω and 10mH). The feeder 1and 2 bus voltages and load voltages are shown in fig.7 and 8.

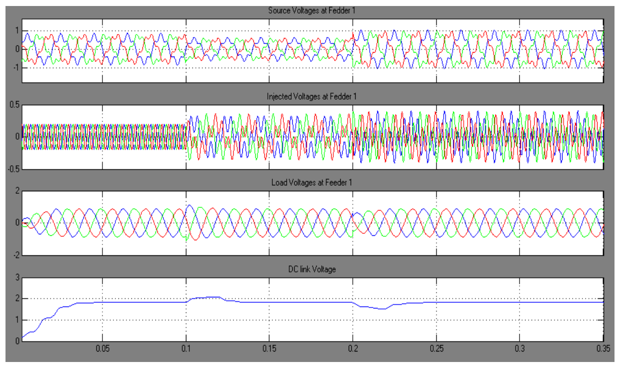

Fig. 7.The phase bus voltage, injected voltage, load Voltages and DC Capacitor Voltage (VDC) at feeder 1

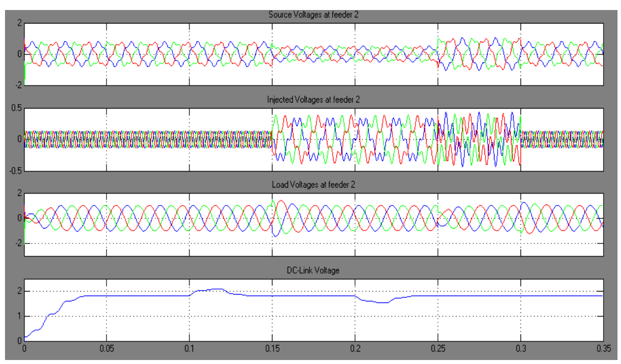

Fig. 8.The phase bus voltage, injected voltage, load Voltages and DC Capacitor Voltage (VDC) at feeder 2

CONCLUSION

In this paper discussesdesign cost optimization of theSynchronous Reference Frame (SRF) based control MC-DVRand regulates of load voltage in adjacent parallel feeder during voltage sag, swell, .faultinterruptionand compare the THD with and without MC-DVRand finally discusses the optimal angle at which series voltage has to be injected so as to have minimum VA loading and optimal of installation cost of MC-DVR are computed by genetic algorithm and Particle Swarm Optimization.

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