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IMPACT OF SVC AND DG COORDINATION ON VOLTAGE CONSTRAINED AVAILABLE TRANSFER CAPABILITY (VSATC)

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ABSTRACT

Rapidly increasing power demand and inadequate generation and transmission capacity have set the trends towards Distributed Generation (DG) and Flexible AC Transmission System (FACTS) aimed at sustainable power delivery. FACTS and DG are often deployed to relieve congestions, improve voltage stability, and enhance transmission capability. However, FACTS and DG placement are often achieved separately. Hence their coordination in power systems operation is paramount for improved power transfer and minimal power losses for optimal power delivery. This paper demonstrates the coordination of SVC and DG in the IEEE 14 bus network for the enhancement of Voltage Constrained Available Transfer Capability (VSATC) and power loss reduction using Multi-Objective Particle Swarm Optimization (MOPSO). Since the objectives are opposite and parallel, hence the need for the transformation of ATC to minimization, which was achieved by negating its value during dominance determination stage. Voltage constrained ATC is obtained using continuation power flow (CPF) and computed at the CPF nose curve. Result show improved ATC with increasing DG penetration level. At high DG penetration (80%), ATC improved by 6.6% while losses reduced by 18.4% when compared to SVC and DG without coordination. Also, the Pareto front of ATC versus power loss indicates parabolic like characteristics.

Keywords: CPF, DG, FACTS, MOPSO, VSATC.

1 INTRODUCTION

Utilities around the world are embracing the market-driven and deregulated framework of the electrical power supply, thereby replacing a percentage of centralised power systems operations. A key feature of deregulation is the open access to transmission infrastructure, which results in the increased volume of the power transfer transaction. The increased in transactions are often constrained by transmission capacity, congestion, and voltage instability(Reddy, 2016; Sharma & Kumar, 2016; Yunfei, Zhinong, Guoqiang, & Yichu, 2015). Consequently, utilities seek to maximise the utilisation of the existing transmission infrastructure. One approach of maximising the utilisation of the existing transmission infrastructure is through optimal deployment of Flexible Alternating Current Transmission Systems (FACTS) devices. FACTS technology enables power flow re-distribution through the use of circuit parameters to relieve congestion, improve voltage stability at load centers, and enhance transmission capability(Ahmad Abubakar Sadiq, Adamu, & Buhari, 2019; Varshini & Kalpana, 2012).

On the other hand, "green politics" and issues of right of way within deregulation also prompt utilities, customers, and power system operators to prefer small capacity generators, connected to the load centers, often called Distributed Generation (DG). The financial risk of DGs is small, and possess technical potentials for ancillary services in addition to meeting load demand (Nwohu, Olatomiwa, Ambafi, Ahmad, & Mogaji, 2017). Therefore, DGs are sited at the distribution level while large wind farms in addition to FACTS at the transmission level (Bavithra, Raja, & Venkatesh, 2016; S Kabir, Krause, Bansal, & Jayashri, 2014; S Kabir, Krause, & Haider, 2014; Shahariar Kabir, Krause, & Bartlett, 2013; Khan, Mallick, Rafi, & Mirza, 2015; Musa, Usman, & Adamu, 2013). Accordingly, a comprehensive assessment of the impacts of FACTS and DG placement in power systems operation to meet the increased power transaction is paramount. A primary index of transmission infrastructure performance and hence the viability of economic transfer transaction is the Available Transfer Capability (ATC) (A.A. Sadiq, Nwohu, & Okenna, 2014).

In (Rahman, Mahmud, Oo, Pota, & Hossain, 2016; Rahman, Mahmud, Pota, & Hossain, 2014), DSTATCOM and DG coordination are demonstrated for reactive power management to improve voltage profile and alleviate the severity of faults. Similarly, (Tolabi, Ali, & Rizwan, 2015) implements a Fuzzy - ACO approach to optimally place DSTATCOM and photovoltaic for power loss, voltage profile, and load balancing. (Venkateswarlu, Ram, & Raju, 2013) Examines the impacts of SVC and DG to increase network loading level and Voltage Stability Constrained ATC (VSATC) using Newton's Raphson (NR) power flow, while (Mahdad & Srairi, 2016) uses adaptive differential search algorithm to optimize the location and sizes of multiple SVC and DG for power loss reduction and voltage deviation. The studies in (Rahman et al., 2016, 2014; Tolabi et al., 2015), ignores ATC enhancement with DFACTS and DG coordination. Although (Venkateswarlu et al., 2013) considered VSATC as critical loading factor, however, the computation of VSATC at the point where NR load flow fails to converge is an infeasible operating condition and the power balance equality constrained is violated; in addition, SVC and DG placement were not optimal but only based on the identified weak bus. In (Mahdad & Srairi, 2016), while a differential search algorithm was used, it did not consider ATC as an objective. This paper, therefore, demonstrates the coordination of SVC and DG in the IEEE 14 bus test network, for the enhancement of VSATC and power loss reduction using Multi-Objective Particle Swarm Optimization (MOPSO).

2 METHODOLOGY

2.1 SVC MODELING

At steady-state operation, the static var compensator (SVC) acts as a source or absorber of VAR. The SVC is therefore modelled as positive or negative load depending on whether it is absorbing or injecting reactive power respectively (A A Sadiq, Adamu, & Buhari, 2019; Venkateswarlu et al., 2013). The equivalent reactive load at the SVC installed bus is given by equation (1) while the modified residual Var is expressed by the equation (2). SVC capacity is constrained according to the equation (3).

$$Q_i^{new} = Q_i^{old} \pm Q_{svc} \tag{1}$$

$$\Delta Q_i^{new} = [(Q_{i,g} - Q_{i,d}) - Q_p^{cal}] + Q_{svc} \tag{2}$$

$$0 \le Q_{svc} \le 100\,MVAR \tag{3}$$

2.2 DG MODEL

In addition to the provision of ancillary service of local bus voltage control, DG is modelled as a generator with maximum and minimum active power capacity constrained by equation (4). Herein, to regulate the local bus voltage, the PQ bus with DG installed is modified into a PV bus.

$$5\,MW \le P_{DG} \le 100\,MW \tag{4}$$

The DG penetration specifies the maximum quantity of active power being injection as a percentage of the total network load (Mahdad & Srairi, 2016) and defines by the equation (5).

$$\sum_{i=1}^{ndg} P_{dg}^i \le \mu \sum_{j \in PQ_{load}} P_{load}^j \tag{5}$$

In the equation (5), the total active power injected by DGs is a percentage of the active power demand, and the penetration is μ.

2.3 CPF FOR ATC

To solve the power flow equation, Continuation Power Flow (CPF) introduces a loading parameter λ to parameterise the power flow equations, thereby avoids singularity and ill-conditioning. The documentation of CPF for ATC assessment is given in (Ahmad Abubakar Sadiq et al., 2019), while at the CPF's nose point, the ATC evaluate to the maximum loading limit as expressed in equation (6), such that the i^{th} bus critical real power loading at the CPF nose point is expressed by the equation (7).

$$ATC = \sum_{i \in \sin k} P_L^{i,cri} - \sum_{i \in \sin k} P_L^{i,base} \tag{6}$$

$$P_L^{i,cri} = (1 + \lambda^{cri}) P_L^{i,base} \tag{7}$$

2.4 MOPSO

In this paper, the problem formulation involves two parallel and opposite objectives: ATC maximisation and minimisation of real power losses, hence a multi-objective formulation. Since the objectives are on two different fronts, there is a need to transform one of the objectives into minimisation or maximisation. Consequently, in the MOPSO algorithm, the ATC is transformed into minimisation by negating its value during the dominance determination stage. For a general minimisation problem, equation (8) defines the minimisation problem formulation of SVC and DG coordination for 2 objectives (Jumaat, Musirin, Othman, & Mokhlis, 2013; Zeinalzadeh, Mohammadi, & Moradi, 2015). The fitness vector of objectives is expressed by the equation (9), which is subject to power flows equality constraints in addition to the constraints equations (3) and (4).

$$\text{minimize } f(x,\lambda) = [f_1(x,\lambda), f_2(x,\lambda)] \tag{8}$$

$$\vec{f}(x,\lambda) = \begin{cases} -ATC = \sum_{i \in \sin k} P_L^{i,cri} - \sum_{i \in \sin k} P_L^{i,base} \\ P^{loss} = \sum_{k=1}^{nl} g_k [V_i^2 + V_j^2 - 2V_i V_j \cos(\delta_i - \delta_j)] \end{cases} \tag{9}$$

3 RESULTS AND DISCUSSION

As a form of validation, the CPF implementation and the methodology described in (Venkateswarlu et al., 2013) were compared and shown in Figure 1. Both CPF and Newton load flow is implemented in MATPOWER 7.0. As shown in Figure 1, both NR and CPF by MATPOWER obtains similar ATC except in the case when Gen4 and Gen5 are the only sources supplying the additional increase in load demand, which is attributed to the generators reaching their respective reactive power limits and hence the likelihood of singularity.

Observe from Figure 1 that, under the case of interest, (with SVC_DG), both approaches obtain similar ATC, with Newton's approach having slightly higher ATC. Consequently, for the active power loss objective, CPF approach is adopted, since the ATC computation at the point where NR fails to converge present an infeasible operating condition; the power losses are therefore not valid as the constraints of power balance equation become violated.

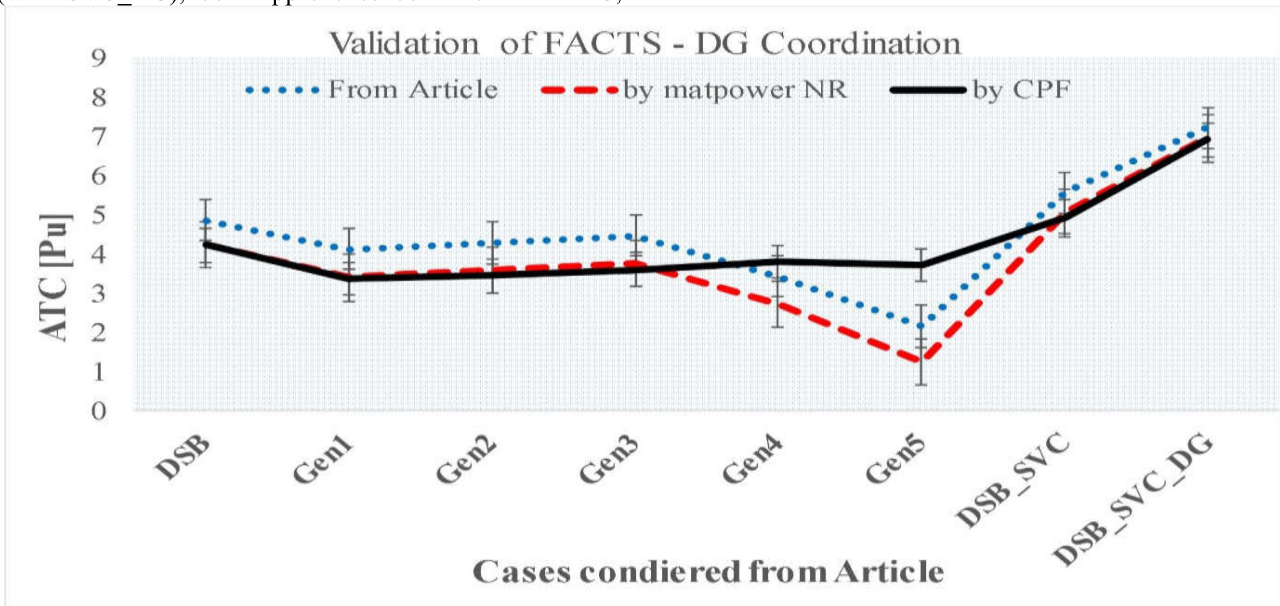

Figure 1: Comparison of NR and CPF approaches

For the multilateral power transfer transaction where all the generators are supplying the increase in load at all the load buses, Figure 2 shows the Pareto front of ATC versus Ploss with different increasing DG penetration. The Pareto depicts a diving shape of, and the ATC increases with the increase in DG penetration.

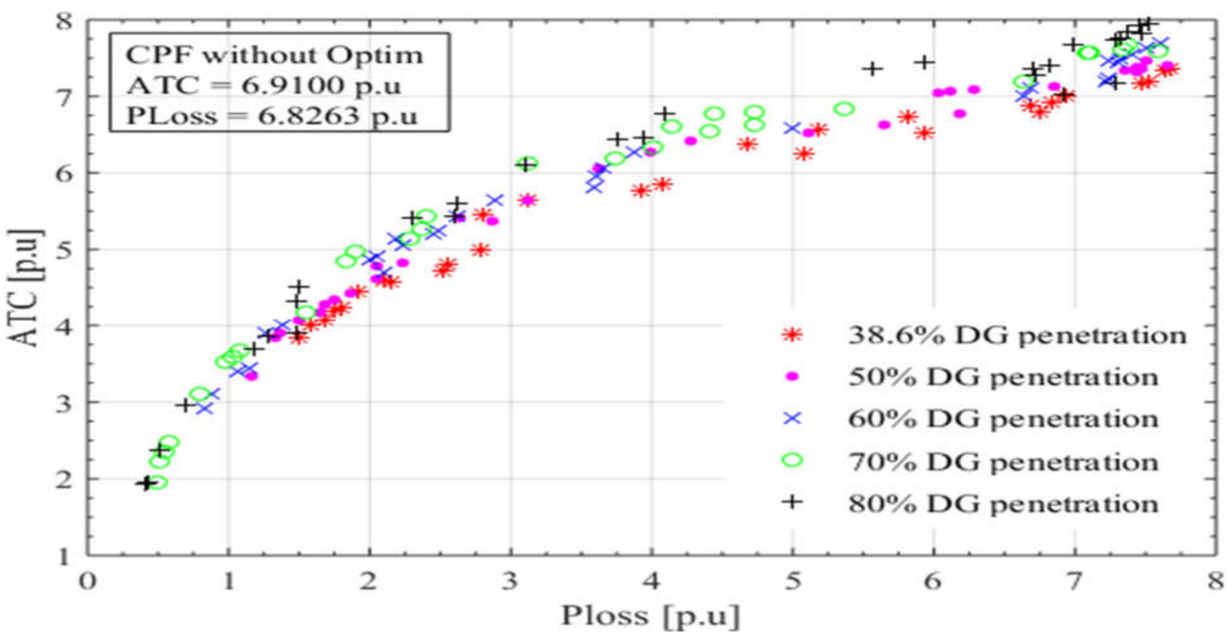

Figure 2: Pareto plot (ATC vs Ploss) for SVC & DG coordination

The Pareto front of Figure 2 with cursor values of nondominated solution within 50% and 80% is depicted in Figure 3. As shown, at 80% DG penetration, the ATC improves to 7.366 p.u with SVC and DG coordination against 6.91 p.u without coordination. Similarly, the active power losses also reduce from 6.826 p.u without coordination to 5.572 p.u with SVC and DG coordination. At 80% DG penetration, the improvement in ATC and reduction in losses represent about 6.6% and 18.4% respectively.

TABLE 1 gives the selected optimal solution of the SVC and DG coordination for 50% to 80% DG penetration.

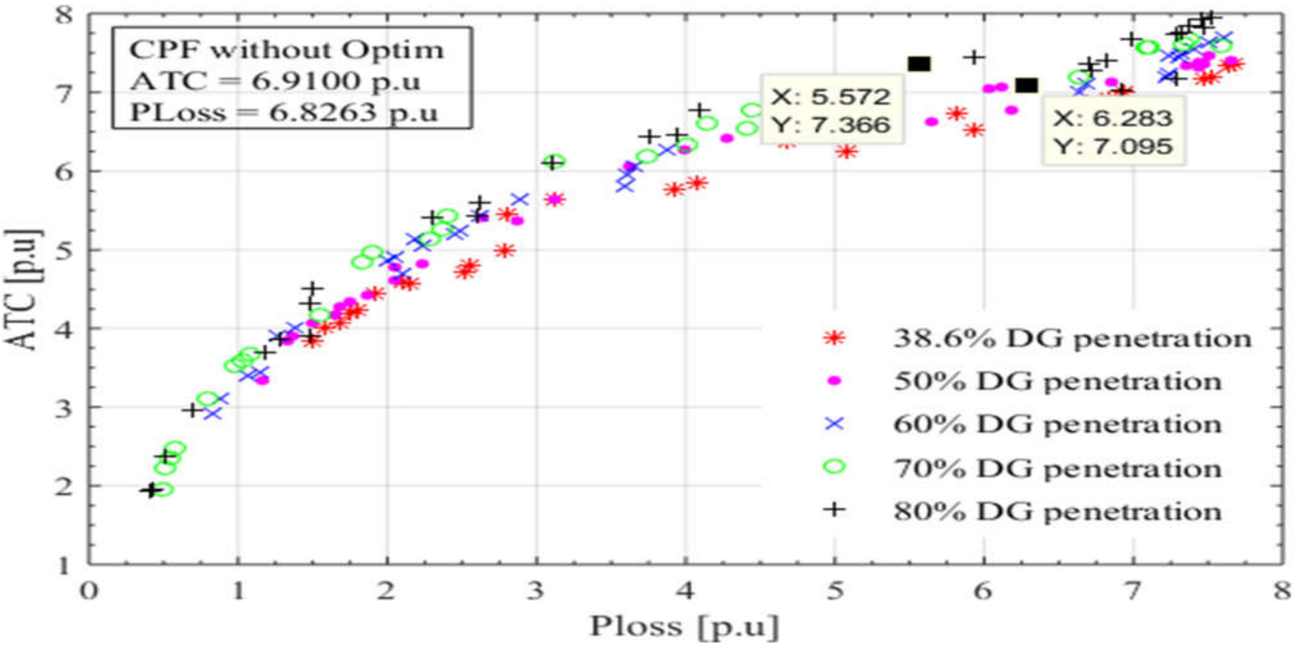

Figure 3: Pareto plot (ATC vs Ploss) with ATC and Ploss cursor values

TABLE 1: SELECTED NONDOMINATED SOLUTIONS FOR VARIOUS DG PENETRATION

% DG	Fitness Values		SVC Solution		DG Solution		
	ATC [p.u]	Ploss [p.u]	SVC bus no.	SVC Size [MVAR]	DG bus no.	PDG [MW]	Vbsvc [p.u]
50	7.09	6.28	14	54.76	9	128.83	1.084
60	7.10	6.68	14	63.60	10	152.93	1.009
60	7.19	6.64	14	58.49	10	181.3	1.009
80	7.36	5.57	14	65.83	7	207.2	1.100

4 CONCLUSION

This paper demonstrates the impacts of SVC and DG coordination for the improvement of VSATC and active power losses. It can be concluded that at higher DG penetration of 80%, for the multilateral transaction where all the generators are supplying the increase in load demand, ATC improves by 6.6% while the active power losses reduced by 18.4% with SVC and DG coordination.

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