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Three-phase transformer arcing horns; neglected deadly components to birds

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Abstract – Unprotected power transformers are known to create electrocution problems for wildlife. However, the role of three-phase transformer arcing horns and bird electrocutions has not been investigated. Arcing horns are rigid conductors sometimes deployed to protect insulators by providing a gap for lightning to jump across without damaging the equipment. To identify how birds are electrocuted by arcing horns we submitted a survey to 32 Iranian utility companies and examined 562 opportunistic utility outage records of bird electrocutions between 2018 to 2019. We documented 59 electrocuted birds and classified five types of arcing horn electrocutions based on where the carcasses were discovered. To mitigate such problems utilities sometimes remove arcing horns but doing so can be problematic to the power network. Using insulation is not entirely effective because the point of the upper rod can produce an electrical discharge to the head of a bird perching on the lower grounded rod. We provide alternative solutions.

Key-words: Avian, electrocution, insulation, lightning arrester, pole-mounted.

INTRODUCTION

Electrocution on overhead power structures negatively affects avian populations in diverse ecosystems worldwide (Ferrer *et al*. 1991, Bevanger 1994, Janss & Ferrer 2001, Ferrer 2012, Kemper *et al*. 2013, Kolnegari *et al*. 2019). Despite the abundance of such occurrences in the Iranian Plateau (Kolnegari *et al*. 2019), studies on conflicts between birds and power lines in Iran are in the preliminary stage and under-represented in English-language publications (Kolnegari *et al*. 2020a). Recently, the establishment of a national group of power technicians and conservationists, along with the implementation of corrective measures on dangerous power structures, have raised public awareness on the issue, placing Iran in a leadership position in the Middle East (Kolnegari *et al*. 2019, Kolnegari *et al*. 2020b).

While the general role of distribution transformers causing bird and animal electrocutions has been widely reported in the literature (Harness & Wilson 2001, Mañosa 2001, Voronova 2012, Demerdzhiev 2014, Dwyer *et al*. 2014, Kross 2014, Hernández Lambraño *et al*. 2018), the interaction of three-phase transformer arcing horns and bird-powerline conflicts has not. Furthermore, reliable corrective measures for these devices have not been adequately addressed.

Arcing horns, also called lightning diverters, protect insulators (i.e. bushings) from damage during overvoltage and flashovers (arcs across insulators) due to lightning strikes, or electrical faults. Arcing horns provide a path for power surges to occur, bypassing the surface of the protected device. These devices are paired on either side of a bushing, one connected to the high voltage component and the other to ground (Pansini 1998, Short 2003). Thus, the primary side of an arcing horn is always energized, and the grounded side is not because it is at earth potential. During an overvoltage event such as a lightning strike, the electricity jumps across the air gap, from the energized phase to the ground (earth). Unfortunately, the gap separation on an arcing horn is such that many animals are large enough to bridge this air gap, which can result in a phase to ground electrocution (EPRI 2001).

In order to better understand avian electrocutions caused by arcing horns of three-phase pole-mounted transformers and to provide possible corrective measures, we conducted a study reviewing electrical power outage data obtained from a survey sent to 32 Iranian electric utility companies. We reviewed two kinds of outage data: permanent faults and transient faults. Utilities record detailed information on permanent faults because they require action to restore power, such as manually replacing a fuse.

Because transient faults are cleared by the system and do not require manual action, record keeping is often less detailed. It is important to include transient outages because less than 10% of avian electrocutions may trigger a sustained outage (Dwyer 2004; Kemper *et al.* 2013). Sustained outages often occur when carcasses do not fall clear but remain hanging between the contact points.

Our objectives were focused on "how arcing horns cause bird electrocutions in Iran", and "what kinds of practices have been employed by Iranian power companies to neutralize the risk to birds". Three-phase transformers with arcing horns used in Iran are also used in other countries from Asia to Africa, and even some European countries (Dasgupta 2002), thus our results may be relevant to other countries. Additionally, we compared this issue to similar problems documented in North America where gapped surge arresters are sometimes deployed. It is recognized there are differences in electrical components between different countries, and North America uses pole mounted transformers which can be arranged as single, two, or three-phase (Harness & Wilson 2001). In Iran three-phase transformers are single contained units. Arcing horns are not used on North American transformers, but similar gapped surge arresters exist. Therefore, mitigation used in North America has relevance.

MATERIALS AND METHODS

Prior to the study, a specialized group of experts was established; Iran's Birds and Power Lines Committee (IBPLC) (Kolnegari *et al*. 2019). To initiate this study IBPLC sent requests to 32 Iranian electric utilities asking for detailed information on outages due to birds occurring during 2018-2019. The request included data on outage locations and dates. The study included power lines throughout Iran which comprises a land mass of 1,648,195 km^2 and has a population of approximately 82 million people. The Iranian power grid consists of 127,581 è km of transmission lines and 815,367 km of distribution lines (Ministry of Energy, 2019). Electricity use is growing by approximately 8%/year (Ministry of Energy, 2019).

This study focused on existing utility records of bird electrocutions associated with distribution power line faults and no necropsies were performed. In order to corroborate incidents were due to electrocution, arcing horn interactions were selected using the following criteria: either bird carcasses were hanging from arcing horns or were noted as contacting them during incident documentation. Current passing through flexor muscles results in a sustained contraction (Hydro Quebec 2020), thus a hanging bird associated with an outage was treated as a suspected electrocution. We interpreted these records and then classified the incidents based on the carcass position on different parts of upper or lower arcing horns. We excluded other carcasses located on transformers from being classified as "arcing horn victims" when they were found away from the lower arcing horns. We also excluded carcasses found on the ground, thus this approach is conservative because it is likely some of the arcing horn carcasses ultimately ended up at the base of the pole. We also noted any proactive measures present which were obtained in the official questionnaire sent to the major Iranian power companies, and in follow up discussions. This information was used to develop suggested practices and to evaluate ongoing corrective methods in Iran.

RESULTS

We reviewed 562 avian incident records provided by 32 Iranian utilities from 2018 to 2019 and found 9.4% of the cases were associated with three-phase transformer arcing horns. These outage records included 59 suspected bird electrocutions, with 49 birds hanging from the arcing horns and 10 birds located on the transformer surface near to lower arcing horns (Table 1). Furthermore, 33 of the records indicated a permanent fault, and 20 a transient fault.

Type of incidents

We classified five types of incidents related to where each carcass was found in relation to the arcing horns (Fig. 1) (*see* Table 1, Type 1 through Type 5). Type 1 consisted of birds perched on the lower –grounded– arcing horn's horizontal support (36 incidents with 40 birds affected), subsequently bridging the gap to the upper energized arcing horns, resulting in a phase to ground electrocution. Raptors including the Common Kestrel *Falco tinnunculus* and Eurasian Sparrowhawk *Accipiter nisus* were involved in this type of incident (Fig. 1B). Type 2 included only long-tailed birds (e.g. Rose-ringed Parakeet *Psittacula krameri* and Eurasian Magpie *Pica pica*) perched on upper energized arcing horns (3 incidents with 3 carcasses), then bridging the gap to the grounded lower arcing horns with their long tails (Fig. 1C). Type 3 occurred when Psittaculidae species climbed from one arcing horn rod to the other rod (4 incidents with 4 carcasses), making simultaneous contact between the energized and grounded parts (Fig. 1D). Type 4 was similar to the first type, but occurred when small birds such as a House Sparrow *Passer domesticus* or Common Starling *Sturnus vulgaris* perched on the

Table 1. Species, number and global IUCN status (LC = Least Concern, NT = Near Threatened, VU = Vulnerable, EN = Endangered) of birds killed by electrocution on arcing horns of three-phase transformers reported by Iranian power companies during 2018-2019. See Figure 1 (Fig. 1A through Fig. 1F) for each incident type

Family	Species	IUCN status	Type of incident					
			Type 1	Type 2	Type 3	Type 4	Type 5	**Total**
Corvidae	Eurasian Magpie *Pica pica*	LC	36	2	-	-	-	**38**
Corvidae	Hooded Crow *Corvus cornix*	LC	1	-	-	-	-	**1**
Sturnidae	Common Starling *Sturnus vulgaris*	LC	-	-	-	5	-	**5**
Passeridae	House Sparrow *Passer domesticus*	LC	-	-	-	4	-	**4**
Alaudidae	Unidentified lark species	NA	-	-	-	-	3	**3**
Psittacidae	Rose-ringed Parakeet *Psittacula krameri*	LC	-	1	4	-	-	**5**
Falconidae	Common Kestrel *Falco tinnunculus*	LC	2	-	-	-	-	**2**
Accipitridae	Eurasian Sparrowhawk *Accipiter nisus*	LC	1	-	-	-	-	**1**
Total			**40**	**3**	**4**	**9**	**3**	**59**

tip of the lower grounded arcing rod (9 incidents with 9 carcasses) then touched their head into the upper energized arcing horn (Fig. 1E). Type 5 was assigned when multiple small birds were electrocuted (1 incident with 3 carcasses). In this situation three small birds (belonging to the lark family, Alaudidae) perching on both upper and lower horns, subsequently interacted with each other and filled the void between the grounded and energized arcing horns (Fig. 1F). Note, this differed from one other multiple incident which occurred when three Eurasian Magpies were killed on a single transformer, but on three different arcing horns (classified as Type 1).

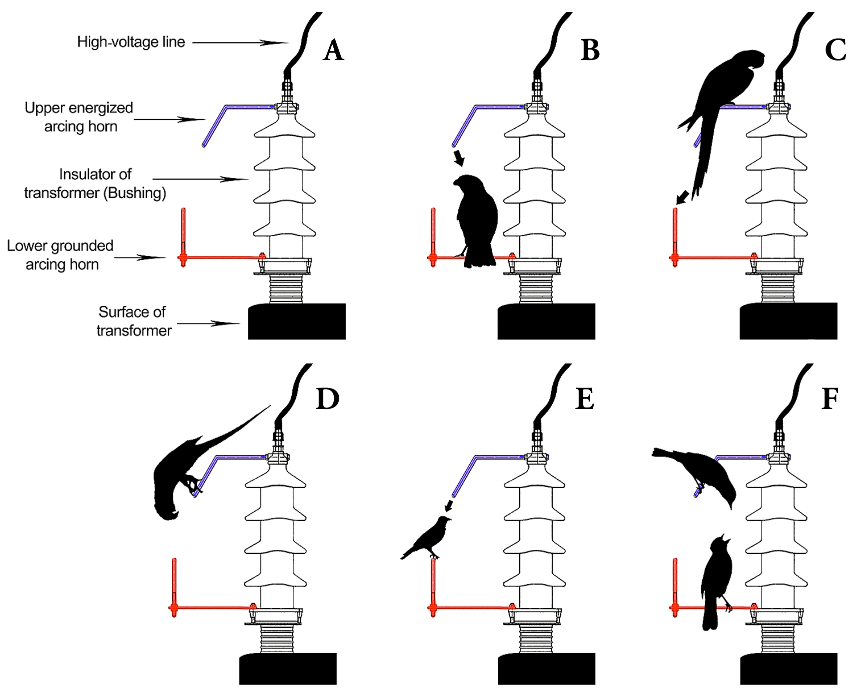

Figure 1. Types of bird electrocution incidents by arcing horns; (A) Medium-voltage transformer bushing and it's arcing horns; (B) Proximity of the bird's head to energized horn and occurrence of an electrical arc from the horn to the bird's head, defined as Type 1; (C) Proximity of the bird's tail to lower horn and occurrence of an electrical arc between them, defined as Type 2; (D) Situation when a parrot comes down from upper horn to lower one, defined as Type 3; (E) Situation when a small bird sits on the peak of the vertical rod of the lower horn, defined as Type 4; (F) Situation when multiple birds interact on arcing horns, defined as Type 5.

DISCUSSION

Bird electrocutions caused by arcing horns is a problem we classified into four types of incidents involving single species. We included a fifth type to include situations where intra- or interspecific interactions occur (Fig. 1F). Such interactions are documented in the literature with a variety of bird species, – Golden Eagles *Aquila chrysaetos* (Schomburg 2003), Common Ravens *Corvus corax* (Ferrer 2010), and a Short-toed Eagle *Circaetus gallicus* with a depredated snake (Guil *et al.* 2018). We suspect the second classification, long-tailed birds spanning the gap with their feathers may be weather dependent. Feathers lose their insulating ability during rain or snow. Dry feathers are good insulators, but wet feathers may be ten times more likely to result in an electrocution (Nelson 1979).

Routine corrective measures

Arcing horns can kill any bird or animal large enough to span the horn gap. The records we reviewed included birds as small as House Sparrows and as large as a Sparrowhawk. Although all the birds were species of Lesser Concern, sensitive species would also be at risk, thus relevant for bird conservation. According to the survey results, 11 out of 32 Iranian power companies (34%) voluntarily avoid using arcing horns in new transformer installations to mitigate possible animal incidents. However, this practice leaves transformers unprotected against overvoltage, therefore this measure is not preferred from an engineering standpoint. Conversely, a more common approach adopted by 66% of power companies is insulating transformer bushings with covers which only partially shield the upper arcing horns. This corrective measure was typically employed during transformer installation. Covering the horns in this fashion can decrease the likelihood of some bird electrocutions, but even with insulation the arcing horns are still exposed and electrical discharges from the upper energized horns to birds perching on the lower rods can still occur. Several birds in our review were electrocuted under this scenario (n=14: containing 9 and 5 incidents related to first and fourth defined types, respectively) (Figs. 2A, 2B and 2C).

Suggested corrective measures

In new construction, transformers can be ordered with internal surge arresters, making the need for external arcing horns unnecessary (NRECA 1996). Another alternative is to use tank mounted surge arresters instead of using arcing horns. When potentially dangerous surges occur, a surge arrester activates and diverts lightning to ground (without a gap), where it disperses harmlessly. Such surge arresters do not have an arcing gap and are more reliable, plus come with protective animal caps (Fig. 2D).

If arcing horns are to be used, consideration should be given to using different types of horns mounted on an isolated perching surface. Among the available types of arcing horns, some of them with sloped rods may be advisable (*see* Kumar 2019). However, from a technical perspective, certain problems will be challenging such as the adjustability of different arcing horns and the specified gap, which change due to varying electrical specifications. And even with a sloped rod, other animals may still be at risk.

Perch discouragers on transmission and distribution lines have been used at a global scale with varying success (APLIC 2006, Ferrer 2012, Dwyer & Doloughan 2014). We considered this method for arcing horns, as well. Unfortunately adding a new device between dense wires of transformers is not practical.

In the United States gapped surge arresters (Fig. 2E) are used on some electrical systems, creating similar outage problems (NRECA 1996). To address the challenge of protecting birds and mammals in North America from bridging the arcing gap, specialized bushing covers are available (EPRI 2019). These bushing covers have a knockout designed to accommodate the grounded arrester strike plate while isolating the energized bushing top (Fig. 2F).

In this study, 75% of the birds (n=59) were electrocuted while perching on the lower horizontal ground rod (Fig. 1B). Therefore, a method to be considered is insulating the lower grounded rod. This simple approach would allow birds to perch on the horizontal rod without allowing a pathway to earth (Fig. 2G). Isolating the ground plane is an approach sometimes used in electrical substations to prevent animal contacts on difficult to cover equipment such as switches (EPRI 2016). The upper rod could also be covered for additional protection. This approach could be taken with solid insulating hose, split seam insulating hose, fusing tape, or shrink wrap. Moreover, it may represent a cost-effective solution however it needs to be tested to ensure the insulation would not affect arcing performance and that insulating materials would withstand electrical stresses. Note, if the insulation is not extended beyond the rod tips, it would still not be effective for the remaining contact types. Another approach would be to build a cover to encase the entire gap.

Regardless of approach, protective covers should be developed using IEEE 1656TM *Guide for Testing the Electrical, Mechanical, and Durability Performance of Wildlife Protective Devices on Overhead Power Distribution Systems Rated up to 38 kV*. Coming up with a solution will not only save wildlife, but also make the system more reliable. The best information available indicates animals

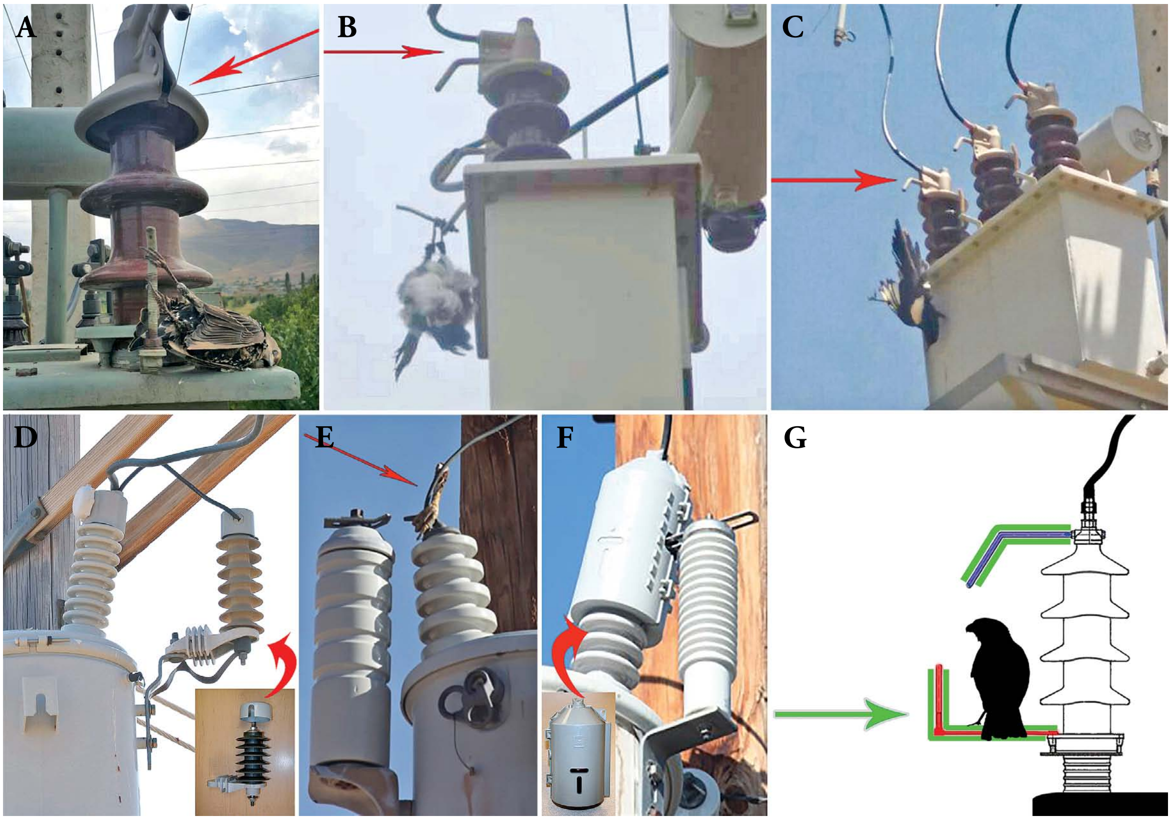

Figure 2. Neutralizing lightning arresters threats to birds: (A,B,C) Bird electrocutions by arcing horns despite using insulating materials on bushings and upper energized rods (note red arrows show insulating materials). (D) Surge arresters can be mounted on transformer tanks to eliminate the need for arcing horns. Note, each surge arrester should be installed with a protective cap and an insulated jumper. (E) Older type gapped surge arrester mounted on a transformer tank. Note bird foot attached to the top of the unprotected transformer bushing. (F) Transformer bushing cover designed with knockout plates to accommodate a gapped arrester strike plate, either horizontal or vertical (colored black), installed on a gapped surge arrester, making it animal friendly. Note, the transformer bushing also has an insulated jumper. (G) Grounded arcing horn covered with tubular insulation to isolate the ground, allowing birds to safely perch on the horizontal insulated rod.

cause nearly one in ten outages (EPRI 2001) and utilities that reduce animal outages experience improved reliability and significant cost savings.

We should also consider why previous literature have dismissed the bird mortality by arcing horns of three-phase transformers. It may be explained by the different types of transformers which do not have arcing horns such as those used in North America and parts of Europe (Dwyer *et al*. 2017, Ferrer 2012). Where arcing horns exist, we believe it is more likely that power line surveyors consider a transformer unit in total, that is the arcing horns are part of the whole rather than a separate unit. Non-utility surveyors may not understand all the nuances of power line equipment thus, an animal on a transformer may simply be attributed to the entire unit which may include jumpers, primary bushings, and arcing horns.

Our study suggests arcing horns cause a significant proportion of electrocutions in Iran, and we do not know if this is a unique problem to this country or if this problem has been overlooked by ornithologists and electrical companies in other countries. Existing mitigation measures using insulation on the energized portion of the horns are also not entirely effective. Accordingly, conservationists should put their effort to encourage power utilities to adopt reliable measures to reduce electrocution risk holistically, including the arcing horns. Ornithologists should also strive to forge partnerships with power companies that may need collaboration to implement measures rooted in avian ethology.

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REFERENCES

Avian Power Line Interaction Committee (APLIC), 2006. Suggested practices for avian protection on power lines: The state of the art in 2006. Edison Electric Institute, APLIC, and the California Energy Commission. Washington, DC and Sacramento, CA.
Bevanger K., 1994. Bird interactions with utility structures: collision and electrocution, causes and mitigating measures. Ibis 136: 412–425.
Cantega Technologies, 2019. What is protecting your assets? Available at: https://reliaguard.com/ [accessed on 15 December 2019].
Dasgupta I., 2002. Design of Transformers. Tata McGraw-Hill Education. New Delhi. India.
Demerdzhiev D.A., 2014. Factors influencing bird mortality caused by power lines within special protected areas and undertaken conservation efforts. Acta Zool. Bulg. 66: 411–423.
Dwyer J.F., 2004. Investigating and mitigating raptor electrocution in an urban environment. MS Thesis, University of Arizona, Tucson.
Dwyer J.F. & Doloughan K.W., 2014. Testing systems of avian perch deterrents on electric power distribution poles in sagebrush habitat. Hum. Wildl. Interact. 8: 39–55.
Dwyer J.F., Harness R.E. & Donohue K., 2014. Predictive model of avian electrocution risk on overhead power lines. Conserv. Biol. 28: 159–168.
Dwyer J.F., Harness R.E. & Duncan E., 2017. Avian electrocutions on incorrectly retrofitted power poles. J. Raptor Res. 51: 293–304.
EPRI 2001. Distribution Wildlife and Pest Control. EPRI, Palo Alto, CA: 2001. Report 1001883.
EPRI 2016. Animal-Caused outages in Substations – Problems and Solutions. EPRI, Palo Alto, CA.
EPRI 2019. Compendium of Animal Caused Outage Prevention Products: 2019 Update. EPRI, Palo Alto, CA.
Ferrer M, 2012. Birds and Power Lines from Conflict to Solution. Endesa S. A. and Fundación Migres. Spain.
Ferrer M., De la Riva M. & Castroviejo J., 1991. Electrocution of raptors on power lines in southwestern Spain. J. Field Ornithol. 62: 181–190.
Ferrer M. & Hiraldo F., 1992. Man-induced sex-biased mortality in the Spanish imperial eagle. Biol. Conserv. 60: 57–60.
Guil F., Soria M.A., Margalida A. & Pérez-García J.M., 2018. Wildfires as collateral effects of wildlife electrocution: An economic approach to the situation in Spain in recent years. Sci. Total Environ. 625: 460–469.
Harness R.E. & Wilson K.R., 2001. Electric-utility structures associated with raptor electrocutions in rural areas. Wildl. Soc. Bull. 29: 612–623.
Hernández Lambraño R.E., Sánchez Agudo J.Á. & Carbonell R., 2018. Where to start? Development of a spatial tool to prioritise retrofitting of power line poles that are dangerous to raptors. J. Appl. Ecol. 55: 2685–2697.
Hydro Quebec, 2020. Safety advice possible consequences of an electrical shock on the body. Available at: https://www.hydroquebec.com/safety/electric-shock/consequences-electric-shock.html. [accessed on 1 January 2020].
Institute of Electrical and Electronics Engineers (IEEE), 2010. IEEE Guide for Testing the Electrical, Mechanical, and Durability Performance of Wildlife Protective Devices on Overhead Power Distribution Systems Rated up to 38kV. Standard 1656-2010 TM.
Janss G.F. & Ferrer M., 2001. Avian electrocution mortality in relation to pole design and adjacent habitat in Spain. Bird Conserv. Int. 11:3–12.
Kemper C.M., Court G.S. & Beck J.A., 2013. Estimating raptor electrocution mortality on distribution power lines in Alberta, Canada. J. Wildl. Manage. 77: 1342–1352.
Kolnegari M., Basiri A.A., Hazrati M. & Dwyer J.F., 2020a. Effects of nest box installation on a distribution power line: Increased Common Kestrel nesting, reduced electrocutions, and reduced electrical faults. J. Raptor Res. 54, *in press*.
Kolnegari M., Moghimi E., Basiri A.A., Qashqaei A.T. & Hazrati M., 2019. A new committee to address the threats of power grids to birds in Iran. Biodiversity 20: 161–164.
Kolnegari M., Moghimi E., Allahdad M., Hazrati M., Basiri, AA., [...] & Conway G.J. (2020) First efforts to address bird collision with power lines in Iran. Sandgrouse, 42, *in press*.
Krass S.M., 2014. Bird electrocutions in New Zealand. Notornis 61: 170–173.
Kumar A., 2019. 16 KVA Distribution Transformer. Available at: https://www.indiamart.com/proddetail/16-kva-distribution-transformer-20826185748.html [accessed on 15 December 2019].
Mañosa S., 2001. Strategies to identify dangerous electricity pylons for birds. Biodivers. Conserv. 10: 1997–2012.
Ministry of Energy, 2019. Extensive information of Iran's power industry. Tavanir Company, Tehran, Iran. [in Persian].
Nelson M.W., 1979. Power lines progress report on eagle protection research. Idaho Power Company, Boise, Idaho.
National Rural Electric Cooperative Association (NRECA), 1996. Animal-caused outages. Rural Electrical Research (RER) 94–95, Arlington, VA.
Pansini A.J., 1998. Electrical Transformers and Power Equipment. Fairmont Press. p. 185. ISBN 978-0-88173-311-2.
Schomburg J.W., 2003. Development and evaluation of predictive models for managing golden eagle electrocutions. MS Thesis, Montana State University, Bozeman.
Short T.A., 2003. Electric Power Distribution Handbook. CRC Press. p. 348. ISBN 978-0-8493-1791-0.
Voronova V., 2012. Assessing the impact of power lines on birds in Central Kazakhstan steppes. Available at: http://www.conservationleadershipprogramme.org/project/impact-of-power-lines-on-birds-kazakhstan/. [Accessed on 16 November 2019].

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